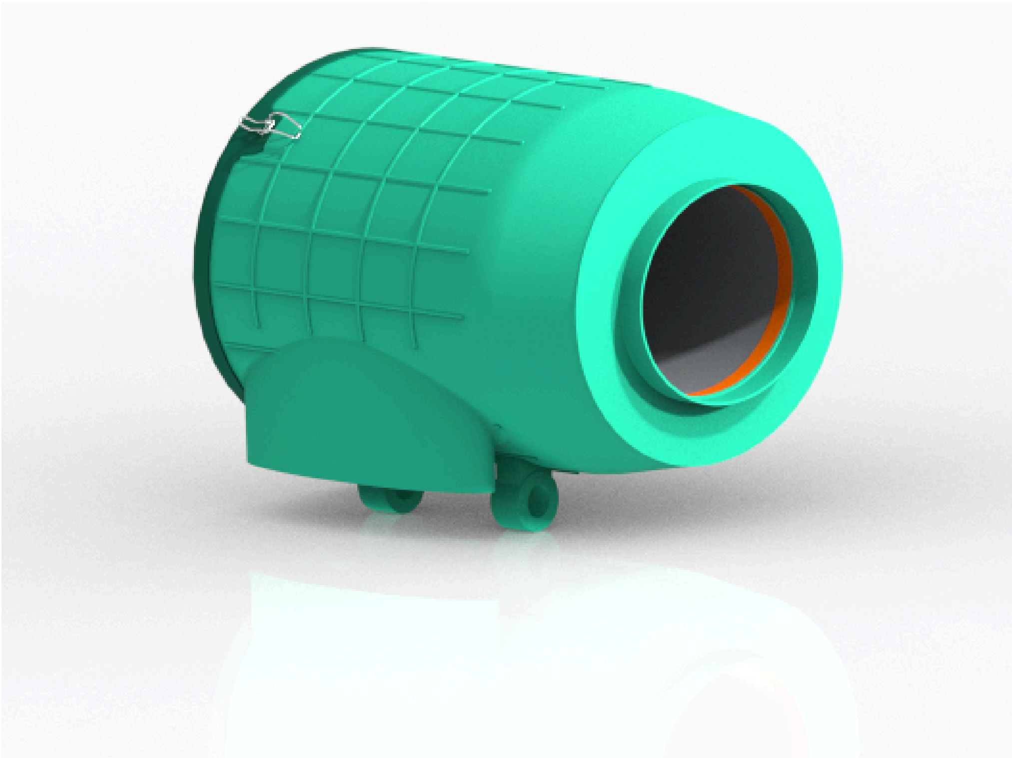

Development of a Higher Capacity Air Cleaner

Conceptual Design of an Air Cleaner for Internal Combustion Engines

Bachelor Thesis

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Abstract

Air filtration systems are essential for maintaining reliable engine performance and long service intervals in heavy-duty trucks operating in demanding environments. This thesis was carried out in collaboration with Volvo Group Trucks Technology with the purpose of developing an air cleaner with increased dust holding capacity for diesel-powered trucks. The objective was to increase the dust holding capacity from 3000 g to 7000 g while maintaining acceptable pressure drop, preserving existing packaging constraints if possible, and ensuring good serviceability and manufacturability.

The project followed a product development process combining both qualitative and quantitative methods. The work included literature studies, benchmarking of competitors, analysis of existing systems, interviews with company experts, and development of a requirements specification. Several concepts were generated through brainstorming, brainwriting, and morphological matrices. The concepts were then evaluated using Pugh and Kesselring matrices to support systematic concept selection.

The final concept achieved the targeted dust holding capacity while remaining within the available packaging space of the truck under the cab. The solution was also developed with consideration for airflow performance, serviceability, and Design for Assembly and Design for Manufacturing. The results demonstrate that it is possible to significantly increase air cleaner capacity without negatively affecting installation complexity or surrounding vehicle systems.

This thesis contributes with a conceptual solution and an engineering development approach that may support future development of air cleaner systems for heavy-duty transport applications.

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1. Introduction

Modern heavy-duty vehicles operate in a wide range of demanding environments where robust engine performance is essential. Air filtration systems are crucial for ensuring reliable engine performance and long service intervals in heavy‑duty vehicles. Operating in demanding environments, the trucks are continuously exposed to contaminants, which can lead to increased wear, reduced efficiency, and higher maintenance requirements in the diesel engine and the air compressor. As transport applications range from clean highway driving to highly dusty off‑road conditions, air cleaning systems must provide reliable and efficient filtration while maintaining acceptable pressure drop and compact packaging.

The challenge lies in significantly increasing dust holding capacity while preserving engine performance, minimizing interference with packaging limitations and ensuring efficient service procedures.

1.1. Background

Volvo Trucks is one of the leaders within the transportation vehicle industry, striving to design innovative solutions emphasizing quality, safety and sustainability. The current air cleaner used in Volvo Trucks' for diesel engines has a dust holding capacity of approximately 3000 g before the filter requires replacement. In practice, the replacement interval is highly dependent on the vehicle's application. Operation in dusty environments, such as sugar cane fields or mining sites, results in significantly more frequent filter changes compared to long-haul transport on highways, where airborne particle concentration is considerably lower.

At the same time, several heavy-duty competitors offer air filtration systems with a dust holding capacity exceeding 7000 g, clearly indicating a development opportunity. Increasing the capacity of the air cleaner would reduce maintenance requirements, lower operating costs and improve vehicle uptime and reliability.

However, increasing dust holding capacity is not simply done by enlarging the filter volume. The available installation space in heavy-duty vehicles is limited, and interference with other components must be minimized.

Furthermore, higher filtration capacity can lead to increased pressure drop across the air cleaner. Excessive intake restriction may negatively affect engine performance, fuel efficiency, and overall system reliability, making pressure drop a critical design parameter. Achieving improved capacity while maintaining acceptable airflow characteristics therefore represents a significant technical challenge.

Continued development of the air cleaner system must consequently balance dust holding capacity, pressure drop, packaging constraints and serviceability. Successfully addressing these aspects has the potential not only to strengthen Volvo's competitiveness but also to support future demands for efficiency, sustainability and reduced lifecycle cost in the company's heavy-duty transport applications.

1.2. Purpose

The purpose of this thesis is to investigate how the capacity of Volvo Trucks' air cleaners for diesel-powered trucks can be increased in order to reduce the need for filter replacements.

1.3. Aim

The objective of this thesis is to develop a conceptual proposal for an air cleaner with increased dust holding capacity from 3000 g to 7000 g for diesel-powered trucks. Furthermore, the objective is to achieve this without compromising cargo space, increasing installation complexity or complicating filter replacement within the air cleaner.

1.4. Research Questions

- How can the air cleaner be designed to achieve a dust holding capacity of a total of 7000 g?
- How can the pressure drop be minimized so that the resistance in the airflow does not exceed 3 kPa when the filter is clean?
- How can the air cleaner be designed so that the total system static pressure drop does not exceed 5.5 kPa at an airflow of 0.7 kg/s with a clean filter?
- Can the new solution be integrated without affecting the cargo space or other system components?
- How should the air cleaner be designed to be optimized for DFA and DFM?

1.5. Scope and Delimitations

- The scope of the work is limited to the air cleaner only.
- Pre-cleaning of the intake air upstream of the air cleaner is outside the scope of this work.
- The work is also limited to using the FH13 truck model as a reference.
- Economic aspects of the proposed solutions are outside the scope of this thesis work.

2. Theoretical Reference

This section presents the theoretical foundation relevant to the development of the proposed air cleaner concept. The presented theories explain the basic processes of air filtration, dust holding and testing procedures.

2.1. Dust Particles

Dust particles present in engine intake air originate from various sources and exhibit a wide range of sizes and geometrical characteristics (Durst et al., 2002). Their shapes may vary from spherical and angular to flat or cuboid, with either rough or smooth surfaces. Particle size distribution is commonly described using standardized size scales.

Mineral particles, primarily quartz (SiO_2), constitute a significant portion of intake air dust (Durst et al., 2002). Their diameters typically range from approximately 0.1 to 2000 µm. Soot particles formed during incomplete combustion can exist either as extremely small individual particles in the nanometer range or as larger clusters between 0.1 and 2 µm (Durst et al., 2002). This size range is particularly critical with regard to component wear, as fine particles are more likely to penetrate filtration systems and contribute to abrasive damage.

2.2. Mechanisms of Particle Separation

Different methods can be used to separate particles depending on their size and shape. Figure 1 shows the interactions between particles and the filter medium (Durst et al., 2002). The filter medium is described as a single fiber whose axis runs perpendicular to the plane of the image. The continuous airflow over the fibers is laminar, as indicated by the curved streamlines where the flow velocity is not constant. Laminar flow is characterized by smooth, parallel layers with a stable and predictable velocity profile, without chaotic fluctuations or mixing between layers. When considerably larger particles approach the fibers, their inertia causes them to leave the streamlines and collide with the fibers, an effect known as inertial impaction.

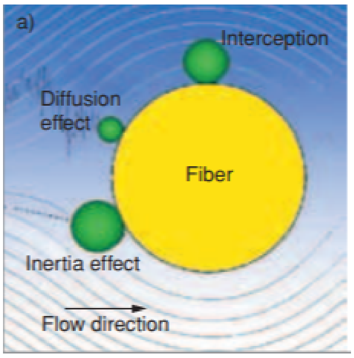

Figure 1: *Schematic representation of particle separation mechanisms occurring at an individual fiber. Source: (Durst et al., 2002).*

Smaller particles, on the other hand, are able to follow the streamlines (Durst et al., 2002). If their diameter is just large enough to touch the fibers, they cling to them through interception, which is a particle separation mechanism in filtration where a particle following an airflow streamline comes into contact with a filter fiber due to its finite size. Interception occurs when the particle's trajectory passes sufficiently close to a fiber, causing it to adhere to the surface without deviating significantly from the flow path. Still smaller particles, with diameters less than about 0.5 µm, also move irregularly in the air flow, called Brownian movement. If these happen to strike the fibers, they are likewise trapped due to diffusion, which is the movement of particles from an area of higher concentration to an area of lower concentration due to random molecular motion. In air filtration, diffusion mainly affects very small particles, which move irregularly and are more likely to collide with and be captured by filter fibers.

2.3. Air Cleaner as a System

An air cleaner is a component in a heavy-duty truck's air intake system whose primary function is to filter out particles, dust and dirt from incoming air before it reaches the engine and compressor. Without this filtration, particles may cause wear on sensitive internal surfaces, reducing the service life of both the engine and the turbocharger.

The air cleaner is a part of the larger air intake system extending from the exterior of the cab to the turbocharger, as seen in Figure 2 further below. Air is drawn in from the top of the cab and travels downward through the snorkel, which is a vertical ducting pipe mounted along the cab's exterior. From the lower end of the snorkel, the air passes through a turn chamber. This portion of the system is referred to as the dirty side and encompasses all components prior to filtration.

Figure 2: *Picture of the air intake system. Source: Internal document.*

The air is then directed into the air cleaner housing, where it undergoes filtration through a cellulose filter medium that captures dust particles. The primary filter is replaced every 24 months or when a pressure drop sensor indicates that the differential pressure has exceeded the acceptable level. Downstream of the primary filter, a safety filter provides an additional layer of protection for the engine. As the quantity of particles penetrating the primary filter is minimal under normal conditions, the safety filter requires far less frequent replacement. Once cleaned, the air is transported onward via an intermediate pipe on the clean side down to the turbocharger ready for combustion.

2.4. Performance Characteristics of Filters

In vehicles, depth filters are the most common types of filters (Durst et al., 2002). They have a structure of several layers of filter surfaces, meaning they trap particles throughout the thickness of the material, not just on the initial surface. The separation of particles happens on the surface of the individual fibers deep inside the texture of the medium. Individual particles initially settle on the surface of the fibers in the beginning of the filtration, but over time the density of the accumulation increases. This allows dendrite-like formations to develop, see the structure in Figure 3 below. These cause the volume of pores available in the filter to decrease, which results in the differential pressure to increase at the same flow. After a certain period of use, the capacity of the filter is exhausted and needs to be replaced.

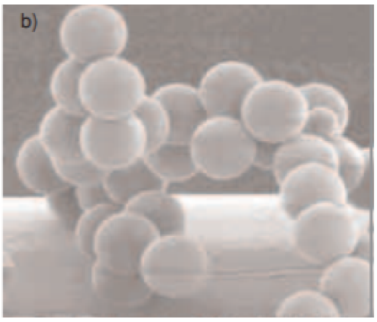

Figure 3: *SEM (scanning electron microscope) picture of a single fiber laden with particles (gas filter) Source: (Durst et al., 2002).*

The increase in the differential pressure in a depth air filter as a function of operating time is shown schematically in the diagram in Figure 4. When a high proportion of the pores in the filter are clogged with particles the differential pressure rises steeply. To prevent the engine from losing power the filter element should be changed before the t_1 limit.

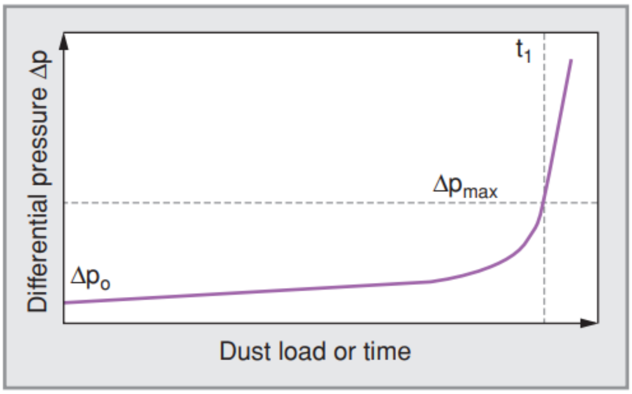

Figure 4: *Schematic description of the increase of differential pressure of a depth filter as a function of dust load or time, respectively. The filter element should be changed at t_1 at the latest (Durst et al., 2002).*

2.5. Dust Holding Capacity

The dust holding capacity (DHC) is the amount of particles a filter media can hold while maintaining the specified efficiency as well as not exceeding the given limitation for pressure drop. (Jin et al., 2017). It describes the filter's ability to function effectively from the clean condition to the end of its service life.

For most filters the efficiency and dust loading are interrelated (Jin et al., 2017). As dust accumulates in the filter, its efficiency increases as well as the pressure drop. The filter efficiency is a measure of the filter's ability to separate particles from the airflow. It describes the fraction of particles of a specific size that are retained by the filter. Filtration efficiency is commonly expressed as $\eta(x_j)[\%]$ where x_j represents the particle size. The efficiency is defined as the ratio of particles captured by the filter to the total number of particles entering the filter at a given particle size. The dust holding capacity is determined as the total accumulated amount of dust captured throughout the entire test period.

2.6. ISO 5011 Fine Dust

The project is developed in accordance with the international standard ISO 5011. It specifies laboratory test methods for engine air cleaners used in internal combustion engines and compressors (ISO, 2025). The standard defines test procedures, test conditions, required equipment and a performance reporting format to enable direct laboratory performance comparison of air cleaners.

The main test areas within ISO 5011 are filtration efficiency which means measuring the efficiency of the air cleaner when filtrating dust from the air intake (ISO, 2025). Furthermore, it also tests dust holding capacity to determine how much dust the filter can hold before reaching pressure drop. Pressure drop is measured through the resistance to airflow at different flow rates. High restriction reduces the engine performance and increases fuel consumption.

2.7. Packaging and Body Builder Interface

In this thesis work, the body builder interface is defined as the geometric boundary delimiting the preferred packaging space for the air cleaner, see Figure 5. Any exceedance of this boundary should be minimized to limit interference with connected systems and installations.

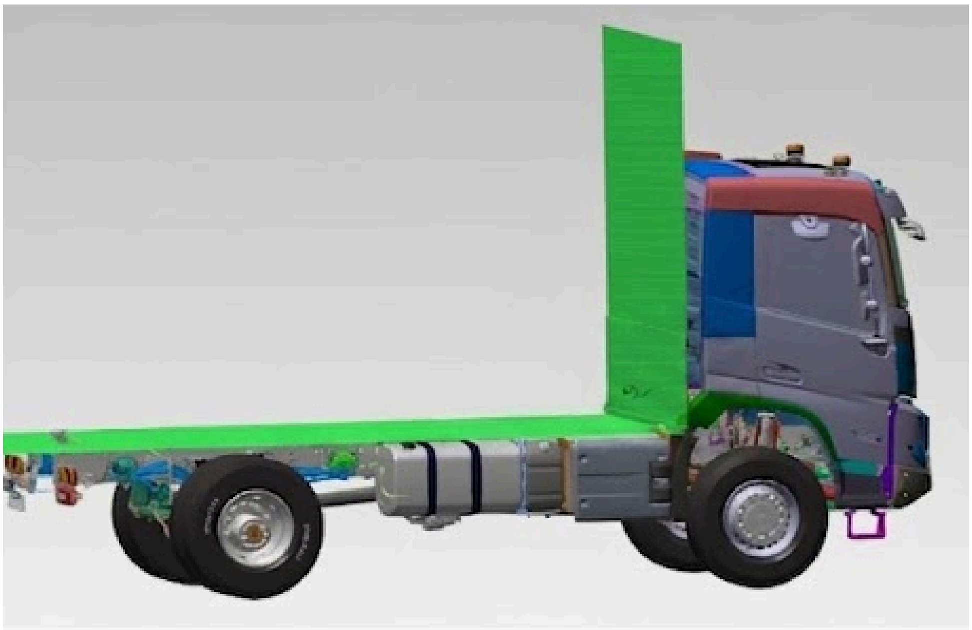

Figure 5: *The image shows the body builder interface in green for the trailer. Source: Own picture.*

2.8. Manufacturing Method of the Air Cleaner Housing

Injection moulding is a widely used manufacturing process for producing plastic components with complex shapes and high repeatability. The process involves melting a polymer and injecting it under high pressure into a mould cavity, where it cools and solidifies into the desired shape (Czepiel et al., 2023). This enables efficient mass production of components with consistent quality and precise geometries.

The process is particularly suitable for high-volume manufacturing due to its automation, short cycle times, and ability to produce large quantities of identical parts (Xometry, n.d.). This makes it well suited for air cleaner housings, which are typically produced in large volumes and require consistent performance.

In addition, injection moulding allows for a high degree of design freedom, enabling the integration of complex features such as ribs, channels and mounting interfaces within a single component (Xometry, n.d.). This is particularly beneficial for air cleaners as the internal geometry plays a key role in guiding the air flow and ensuring proper distribution through the filter. Integrating these features directly into the housing reduces the need for additional components and simplifies assembly.

However, the quality and performance of the final component are influenced by process parameters such as temperature, pressure and cooling time. These factors affect how the material flows, fills the mould, and solidifies and are therefore critical in achieving the desired mechanical properties and dimensional accuracy (Czepiel et al., 2023). For air cleaners, maintaining tight tolerances and structural integrity is important to ensure proper sealing and reliable usage over time.

2.9. Fluid Dynamics

The airflow through an air cleaner is influenced by both the filter media and the geometry of the air cleaner housing. As air passes through the system, a pressure drop occurs due to the resistance to airflow imposed by the filter media and the air cleaner geometry. Pressure drop is an important design parameter, as it affects the operating conditions of the air intake system.

The flow through the filter can be described as flow through a porous medium, where the material structure, porosity and permeability determine the resistance experienced by the air. At the same time, the surrounding geometry, including the inlet, outlet and internal channels, has a significant impact on flow distribution, separation and the level of turbulence within the system.

At the flow rates typical for this type of application, the flow is generally turbulent. This means that energy losses arise not only within the filter material but also due to vortices and flow separation caused by the geometry. Therefore, it is important to consider both the filter properties and the geometric design to achieve a comprehensive understanding of the total pressure drop in the system.

3. Methodology

The project was conducted according to an engineering development process, where various methods are applied to investigate the composition of the air cleaner, Volvo's existing components, as well as solutions used by competitors. To gain a deeper understanding, interviews were conducted and a requirements specification was developed. The methodology also includes idea generation, concept development and concept evaluation prior to concept selection and visualization. Both qualitative and quantitative approaches are employed, and the methodology is adapted for product development within the automotive industry.

3.1. Information Gathering and Literature Study

A literature study is a method used to collect and analyse existing information within a given field. The method involves studies of both internal and external sources of information to understand the subject. Internal sources include company documentation such as technical standards, reports, design guidelines and material from previous projects. External information gathering is conducted through benchmarking and review of publicly available material. Benchmarking involves analysing existing solutions from competitors to analyse different design approaches and technical solutions. This can include investigating scientific publications, patents, product documentation and physical examination of existing products.

The purpose of the literature study is to create a broad and structured understanding of the current state of knowledge. This means identifying relevant technologies as well as limitations.

3.2. Requirements Specification

The requirements specification is a structured method used to define and document the requirements and desired characteristics of a product or system. These requirements typically address functionality, performance, usability, manufacturability, reliability and system integration. The requirements may be delivered from multiple sources, such as the company, customers needs, suppliers and laws.

The process involves identifying, formulating and structuring requirements so that they are measurable and specific. Requirements are often categorized as mandatory requirements or desirable criteria in order to prioritize and evaluate them.

The requirements specification is used as a reference later throughout the product development process. It supports decision-making by providing a basis for concept generation, evaluation and selection, ensuring that proposed solutions are aligned with defined needs and criterias.

3.3. Semi-structured and Unstructured Interviews

Semi-structured interviews are based on a predefined set of themes or questions, ensuring that key topics are consistently addressed across interviews. At the same time, they allow the interviewer to ask follow-up questions and adapt the conversation based on the responses, enabling a more in-depth exploration of specific areas.

Unstructured interviews do not follow a fixed set of questions since they are instead guided by the experts' responses. This method is used to capture detailed insights, personal experiences and perspectives that can be difficult to capture through more structured methods. It allows for open-ended discussions, which can reveal unexpected information and contribute to a broader understanding of the subject.

3.4. Brainstorming and Brainwriting

Brainstorming and brainwriting are methods used for idea generation in the early stages of a development process. Both methods aim to explore a wide range of possible solutions and to broaden the solution space before concepts are evaluated and refined.

Brainstorming is used as a tool where participants generate ideas in a group setting. The method encourages the free flow of ideas, where all suggestions are considered without immediate criticism or evaluation. This approach allows a large number of ideas to be generated in a short period of time.

Brainwriting is a more structured method in which participants generate ideas individually by writing them down before sharing with each other. This reduces the risk of participants influencing each other and allows all individuals to contribute and think freely. The ideas are discussed after the individual phase, supporting a diverse collection of suggestions.

3.5. Morphological Matrix

A morphological matrix is a systematic method used to generate concept solutions by combining different sub-solutions. The method involves decomposing a product or system into its main functions and identifying multiple alternative solutions for each function. These alternatives are then organized in a matrix, where each row represents a function and each column contains possible solution principles.

By combining one alternative from each function, a variety of complete concept solutions can be generated. It is particularly useful for ensuring that a wide range of potential solutions is considered before proceeding to concept evaluation and selection.

3.6. Pugh Matrix

A Pugh matrix is used to evaluate and compare different concept solutions relative to a reference concept. The reference concept is often represented by an existing solution and serves as a benchmark against the newly developed concepts.

The evaluation is made by a comparison based on criterias from the requirements specification. Each concept is qualitatively compared to the reference by indicating whether it performs better, worse, or equal for each criterion. This enables a systematic assessment of the strengths and weaknesses of each concept.

The Pugh matrix supports objective comparison by providing a clear evaluation framework. It identifies promising concepts and highlights areas where improvements may be needed, therefore serving as a basis for concept selection and further development.

3.7. Kesselring Matrix

A Kesselring matrix is a quantitative evaluation method used to determine the most suitable concept based on a set of predefined criteria. The method builds upon a weighted assessment, where each criterion is assigned a relative importance prior to the evaluation of the concepts.

The weighting of criteria is commonly performed using pairwise comparison. In this process, each criterion is systematically compared with all others to assess their relative importance. If one criterion is considered more important than another, it is assigned a value of 1. If it is considered less important, it is assigned a value of 0 and if both are considered equally important, a value of 0.5 is assigned. The values are then summed for each criterion and normalized to obtain weighting factors.

These weighting factors are subsequently applied in the Kesselring matrix, where each concept is evaluated against the defined criteria. The method provides a structured and transparent approach for comparing concepts and supports objective decision-making by combining performance ratings with the relative importance of each criterion.

3.8. Use of Generative AI Tools

ChatGPT (OpenAI, GPT-5.5) was used as a language support tool during the preparation of this thesis. Its use was limited to assistance with grammar correction, spelling, phrasing and general formal language refinement. It was not used to generate technical content, conduct analysis, provide factual information or influence the project’s methodology, results or conclusions. All technical content, engineering decisions, analyses and interpretations presented in this report were developed and verified independently by the authors.

4. Results

This section presents the results obtained during the thesis project. The findings are based on the conducted data collection, analyses and concept development activities described in the methodology. The results are structured to reflect the progression from identified needs and requirements to the final concept selection.

4.1. Research Findings

The research was conducted with a focus on Volvo's current air cleaner solution, as well as alternative media that could be used in the filter to increase dust holding capacity. A competitor analysis was conducted for inspiration in similar applications. Additionally, the filter area of Volvo's air cleaner as well as pleat configurations were analyzed in relation to the face velocity of the airflow.

4.1.1. Existing Air Cleaner Design in Volvo Diesel Trucks

Volvo Trucks' current air cleaner for combustion engines has a dust holding capacity of 3000 g before filter replacement is required according to engineers in the Air Intake team (personal communication, 2026). The actual replacement interval is highly dependent on the vehicle's operating conditions, where operation in dusty environments such as sugarcane fields results in significantly more frequent filter replacements compared to long-distance highway transport. Several competitors offer air cleaning systems with dust-holding capacities exceeding 7000 g, indicating a clear need for further development. Increasing the dust-holding capacity would contribute to reduced maintenance requirements and improved operational reliability. Further development of the air cleaning system may strengthen Volvo's competitiveness and support the fulfillment of future requirements related to efficiency and sustainability.

The current air cleaner is cylinder shaped in regards to both the housing as well as filter media. The dimensions of the housing have an outer diameter 383 mm, length of 428.5 mm and wall thickness of 3.5 mm. The housing is in the material PP30GF which is polypropylene with 30% glass fibre, making it resilient for the vibrating conditions in the truck (personal communication, 2026). The design has ribs for reinforcement making it resistant to movements and vibrations. The filter cylinder is modular so it can be replaced during service. The lid of the housing is therefore constrained with fasteners, making the service process efficient.

The current filter cylinder has an outside diameter of 326 mm and a pleat height of 58 mm. The cylinder height is 350 mm and the number of pleats are 338. The filter surface is 13.73 m^2 and the total filter volume is 17,09 liters, see the housing and filter in Figure 6 below. The space between the housing and the filter varies between 40 mm and 20 mm, allowing the air to flow without a high amount of pressure building up.

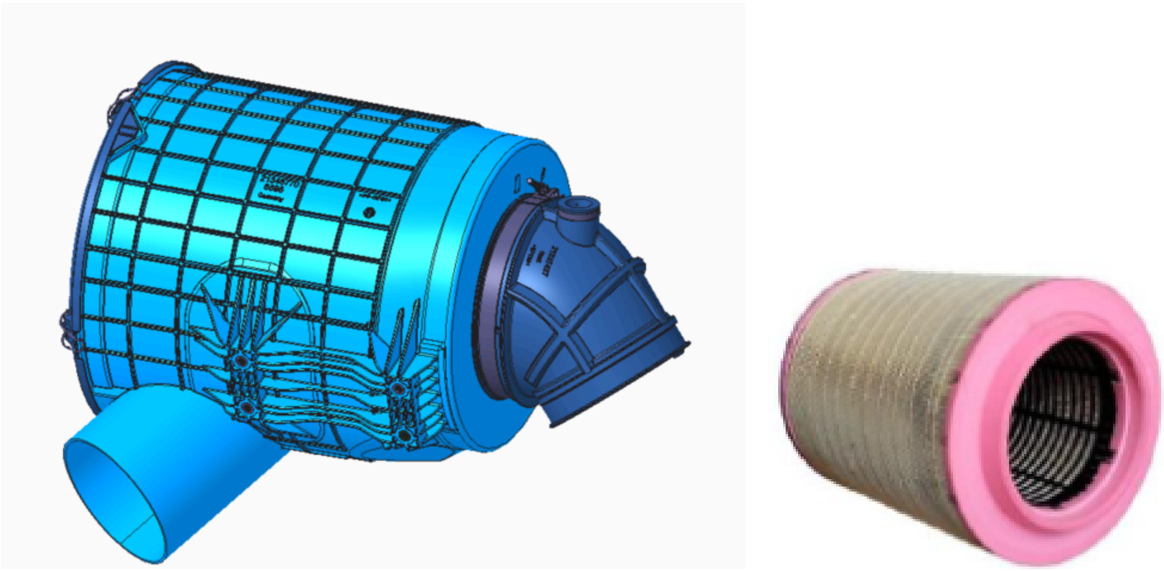

Figure 6: *The air cleaner currently used in Volvo diesel trucks, including the filter. Source: Own picture.*

4.1.2. Potential Filter Medias

Several different filter media were researched in order to find the most suitable for the requirements stated. Due to packaging limitations in the truck it is beneficial with a filter media that can hold an increase of dust per volume unit in comparison to the current filter media. At the same time, the filter media has to be compatible with the face velocity of the airflow as well as fulfilling the requirements of maximum allowed pressure drop in the air cleaner.

Woven Media - Cellulose

In the currently used air cleaner the filter part is of a woven media. This means it consists of an even pattern of cellulose that is folded into pleats, making the absorption area larger for optimal DHC (Durst et al., 2002).

Cellulose+

A thinner woven cellulose material, provided by one of Volvo's manufacturers, referred to in this report as Cellulose+, has potential for up to 25% higher dust holding capacity compared to conventional cellulose (personal communication, 2026). This is made possible by the thinner material, enabling more pleats in the same installation volume.

Non-woven Media

Non-woven air filter media is composed of randomly oriented synthetic fibers, normally polyester (Durst et al., 2002). In contrast to cellulose papers, the synthetic non-wovens are manufactured with a graded structure where the medium is more open with larger pores up stream and much more dense on the down stream side. This allows separation of dust particles within the thickness of the medium and leads to improved dust storage since all the particles do not get stuck together at the surface blocking the air flow. Instead, larger particles get stuck early on in the filter material while smaller particles travel further down the filter and are only caught once the media is dense enough. For a comparison between non-woven and woven material, see Figure 7 below.

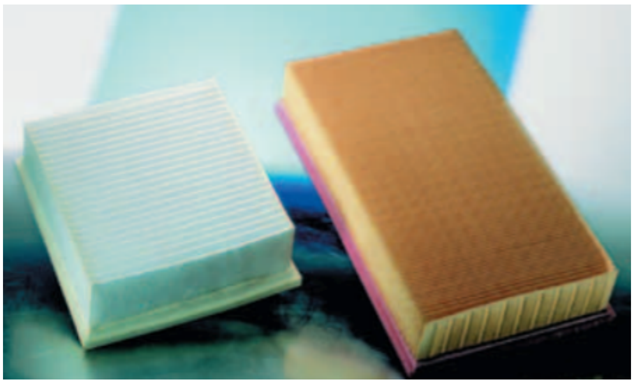

Figure 7: Non-woven and woven material. Source: (Durst et al., 2002).

While standard cellulose papers reach dust holding capacities up to 220 g/m², high-efficiency graded non-wovens achieve about 900-1100 g/m² at the same filtration efficiency (Durst et al., 2002). In practice, ISO 5011 tests show that synthetic non-woven filters can hold up to 50% more dust than cellulose filters in the same installation space. High-efficiency non-woven material also requires 35% less space than a cellulose filter while providing the same dust holding capacity and filtration efficiency.

The higher dust holding capacity of the filter media directly benefits pressure drop behavior which is beneficial for energy efficiency (Durst et al., 2002). As the dust is stored throughout the depth of the media rather than forming a surface cake, pore clogging is delayed and the steep rise in differential pressure of depth filters occurs later in the service life. Non-wovens can also operate at higher specific volumetric flow rates than paper while maintaining at least the same filtration efficiency. This means that low pressure drop can be maintained despite compact designs of the air cleaner.

Nanofibre coated filter media

In order to increase the filtration efficiency of a non-woven filter media, a nanofibre coat can be added on the downstream side of the filter (Trautmann et al., 2006). This means excellent engine protection from the smallest particles in conditions with soot and atmospheric air. In combination with the design of compact air filter elements, it is possible to achieve an increased filtration performance compared to the available standard cellulose filter media when thinner base paper and the nanofibre coating are combined.

4.1.3. Filter Area

The filter area is an essential factor for dust holding capacity. The amount of dust the filter can hold is directly proportional to the total filter area in combination with the specific dust holding capacity of the material. The total filter area is determined by pleat patterns and embossing, as well as size limitations in the truck. Filter area is a crucial aspect to consider when designing the air cleaner.

4.1.4. Pleat Patterns

Pleat patterns are the arrangement of folds of the filter media. The main advantage of pleat patterns is the ability to fit more filter area in a smaller package which is essential for dust holding capacity as well as filter efficiency.

To create stable and consistent pleats, cellulose filters are impregnated which also helps the material withstand environmental factors and extend its life time. On the other hand, cellulose still has a limited life span of five years due to the brittle nature of the material. However, this is well over the recommended replacement time of air filters on Volvo’s current air cleaners of once every 24 months (personal communication, 2026).

Embossing of the material also helps with stability, this is especially important in synthetic filter media that is not impregnated. Embossing creates small patterns in the material which helps with stiffness (Durst et al., 2002).

Optimization of pleat patterns in accordance with the chosen filter material is an important aspect that needs to be handled when designing the air cleaner configuration (Durst et al., 2002).

4.1.5. Face Velocity

Face velocity is the speed the air travels through the filter surface, and is a key parameter for both filtration efficiency and the practically usable dust holding capacity of an air filter (Durst et al., 2002). The filter area is chosen so that the airflow speed does not exceed a critical value, where particles no longer reliably attach to the fibers but tend to bounce or be re-entrained. Re-entraining happens when already filtered particles are released from the fibres and follow the air flow once again. This sharply reduces filtration efficiency and accelerates local clogging (Xu, 2013). In practice, this means that high face velocity leads to non-uniform dust collection, faster pressure-drop build-up and therefore a lower dust holding capacity before the allowable final Δp is reached.

Dust holding capacity is directly tied to the time needed for the pressure drop to increase to a specified multiple of the initial value, and that this lifetime scales inversely with flow rate Q and thus with face velocity for a given area (Xu, 2013). When Q is increased, the filter reaches its standard dust holding capacity at a time, and pressure drop rises more steeply with dust load once filtration velocity exceeds the nominal range (Xu, 2013). This means that in order to maximize dust holding capacity, the filter must be designed with sufficient area and appropriate pleat geometry so that face velocity stays below the critical value and the dust load is distributed uniformly across the medium.

4.2. Wishes of the Brand

To get a deeper understanding of Volvo's wishes regarding the development of an air cleaner with a higher dust-holding capacity, an interview with the brand was held, see Appendix 1. The brand is a department within Volvo Group that makes larger decisions regarding how the company should move forward and what strategies and focus areas it should have. Two engineers representing the Volvo brand participated and explained the motive behind the wish for a developed air cleaner, as well as what Volvo prioritizes if sacrifices have to be made to the current solution.

The engineers from the brand explained that the air cleaner is a maintenance part on the truck. Depending on the environment the truck is being driven in you have to change the air filter with different intervals. In dusty environments, especially in mines in Indonesia and India, the filter gets clogged much faster and has to be changed sooner than what is normally expected, they change filter approximately 20 times per year. Since the filters provided by Volvo are expensive, customers often turn to competitors when exchanging the filter. This is something the brand wishes to change by developing an air cleaner with increased DHC that has longer service intervals meaning more convenience for the customer as well as not having to buy as many filter parts.

The purpose of increasing the DHC is so that the filter should not have to be changed as often as they are today in dusty environments such as mines. The brand discussed different possible solutions in order to prolong the time between having to change the filter. An effective solution is to have a pre-cleaner incorporated before the air filter in order to eliminate a high amount of dust particles from the air intake before even reaching the actual air filter. However, the air filter has the requirement of having a DHC of 7000 g, which is what this thesis work would emphasize since it is limited from developing any type of pre-cleaner.

According to Volvo's current research a dual air cleaner, consisting of two cyclones would be an effective solution since 7000 g DHC was calculated to be too high of a mass for a single cyclone to absorb effectively with the filter media used today. However, a dual air cleaner is not the most cost effective design. The brand explained that the goal is to develop a solution for robust trucks in mining areas in Australia, India and Indonesia that are moving heavy materials. It was calculated that the air cleaner would be more expensive than the current solution. But since the target group is willing to invest in a more expensive Volvo truck it is not seen as a problem. The brand also explained this type of air cleaner would have to be bigger in volume than the current design, meaning it will interfere with the body builder interface. Since it is a special application it would be beneficial for the trucks in mining to sacrifice a small part of their loading area in order to increase the DHC since having the truck out of service is what is most expensive for the customers.

4.3. Interview with an Air Intake Specialist at Volvo

In order to get an understanding of technical details and obtain a broader background description of the problem an interview was conducted with an air-intake specialist, see Appendix 2. The interview was in a semi-structured manner, see description of this method in the methodology section, with an interview guide as a point of reference but with room for open discussion of the topics. The following are insights taken from the interview.

Previous attempts to implement an air cleaner have been denied mostly due to high "Supplier Involvement in Product Development" (SIPD) costs.Manufacturing costs are another major reason, which heavily depends on the production volume. Lower volumes allow for more expensive solutions, which is more suited for molding, while other manufacturing strategies are more appropriate for larger volumes. Manual labour is expensive in Sweden so manufacturing requiring a few man hours is to be preferred.

Currently, the air cleaner is installed in the main assembly flow, shortly after the engine is lowered into the chassis. It is bolted onto brackets, after which an aluminium pipe and then a rubber turbo hose are mounted on the clean side of the air cleaner. The cab arrives later on the line and must then be aligned with this connection pipe, which is initially left slightly loose and finally positioned by tightening the nuts; one of the screws can only be tightened using a step ladder, which impairs accessibility. GTO, who are the part of Volvo Group that assembles the trucks, would prefer to have the air cleaner pre-mounted on the engine/gearbox assembly to reduce work in the main flow, but this is today only feasible for short cabs.

Changing the air filters on trucks with a 13 litre diesel engine can be carried out by tipping the cab, opening the air cleaner and replacing the filter, the whole process taking around 4 minutes. On the 17 litre diesel engine trucks screws have to be loosened on both the clean and dirty side, as well as a console which allows access to the filter. This process instead takes 30 minutes, something that would be preferred to decrease. The general recommendation of replacement frequency is 24 months but the actual rate varies greatly depending on field of usage. The interviewee highlights a mining business in Brazil that changes the filter every 5 weeks, although this is too often, it is better than risking turbo or engine failure. A sensor exists that alarms the driver when the pressure drop on the clean side of the air cleaner surpasses 5,5 kPa, indicating a filter replacement is necessary.

The dust holding capacity is tested by the air cleaner suppliers, which at the moment are two companies. They have special testing equipment and information about filter materials is generally quite secretive.

Discussions about switching to activated carbon filters have been held due to them also removing chemicals and pollen. High costs prevented them from being implemented. Currently filters are made up of cellulose the interviewee believes that filter media is an area with potential for improvement.

4.4. Competitor Analysis

In order to support the development of an air cleaner with increased dust holding capacity, a competitor analysis was conducted to investigate how other heavy-duty truck manufacturers approach air cleaner design for demanding operating environments. The investigation focused primarily on solutions from Mercedes-Benz and Scania, with the purpose of identifying design strategies, packaging solutions and target performance levels relevant to the project.

Some heavy-duty filtration systems, particularly those used in harvesting and off-road machinery applications, utilize multicyclone pre-separators to improve contaminant separation before the airflow reaches the main filter, as seen in Figure 8 (Volvo Group Trucks Technology, 2021). These systems can significantly increase dust holding capacity and extend service intervals while reducing the load on the primary filter element.

Both Mercedes and Scania offer air cleaner systems capable of achieving dust holding capacities around 7000 g (Volvo Group Trucks Technology, 2021). A common design characteristic identified during the competitor analysis was the use of dual filter elements mounted behind the cab, allowing significantly larger installation volumes compared to the packaging space available beneath the cab in the Volvo platform investigated during this project.

Figure 8: *The illustration shows air cleaner and pre-separation of Scania R560 and Mercedes Benz Daimler Actros Source: Volvo Group Trucks Technology (2021).*

4.4.1. Mercedes-Benz

The Mercedes-Benz Actros truck is equipped with an air cleaner system with a dust holding capacity exceeding 7000 g (Volvo Group Trucks Technology, 2021). The system consists of two cyclone pre-separators together with two cylindrical filter elements, illustrated in Figure 9. Optional safety elements can also be added. According to the available information, the air cleaner is manufactured using rotational moulding technology in Germany.

Figure 9: *Dual air cleaner behind cab of Mercedes Benz truck. Internal Volvo Group presentation material, no longer publicly available.*

The air intake system of the Actros is designed for demanding operating and climate conditions. The intake is positioned at the upper part of the cab together with a cyclone pre-filter system, which according to Mercedes documentation can remove up to 80% of dust particles and larger contaminants before the air reaches the primary filter element. This contributes to extended filter lifetime and reduced maintenance requirements (Mercedes-Benz, n.d.).

According to maintenance documentation for the Actros and Arocs platforms, the air filter replacement interval is specified to approximately 120,000 km under the intended operating conditions (Mercedes-Benz, n.d.).

4.4.2. Scania

Scania has also developed high-capacity air cleaner systems capable of achieving dust holding capacities around 7000 g for demanding operating environments (Volvo Group Trucks Technology, 2021). Similar to the Mercedes solution, Scania utilizes a dual air cleaner configuration together with integrated self-cleaning cyclone pre-cleaners, which can be seen in Figure 10.

a) 

b) 

Figure 10: *Picture a) and b) shows a dual air cleaner behind the cab of Scania trucks. Internal Volvo Group presentation material, no longer publicly available.*

The available documentation also highlights the importance of airflow management and pressure limitations within the intake system (Scania CV AB, 2018). Requirements regarding intake line dimensions and maximum permissible vacuum levels indicate that maintaining low flow resistance is an important aspect of the overall air cleaner design.

Overall, the competitor analysis showed that pre-separation systems are commonly used in high-capacity air cleaner solutions intended for demanding operating environments. Both Mercedes-Benz and Scania utilize dual air cleaner configurations together with cyclone-based pre-separation systems in order to reduce the load on the primary filter elements and extend service intervals. Another common characteristic identified was that both solutions are mounted behind the cab, allowing significantly larger installation volumes compared to the available packaging space within the investigated Volvo platform. The competitor analysis therefore highlighted the importance of installation volume, airflow management and pre-separation in achieving dust holding capacities around 7000 g in heavy-duty applications. However, pre-cleaner solutions were not considered in this project due to a delimitation set in the early stages of the thesis work.

4.5. Function Analysis

Table 1: Definition of function classes.

HF	Main Function
SF	Supporting Function
DF	Design Function
M	Mandatory
D	Desired

The function analysis shows the function the air cleaner requires or desires, see Table 2. This is a base for the requirement specification. See the definition of the classes below in Table 1.

Table 2: Function analysis for the air cleaner.

Function Analysis				
Function		**Class**	**M/D**	**Note**
Filter	air	MF	M	
Direct	air	SF	M	
Enable	replacement	DF	M	Of filter.
Indicate	clogging	DF	M	Sensors on the clean side.
Minimize	pressure drop	DF	M/D	Maximum 5,5 kPa.
Stabilize	flow	SF	D	
Prevent	re-entrainment	SF	M	
Utilize	filter surface area	SF	D	
Seal	system	SF	M	
Secure	filter	SF	M	
Meet	size requirements	DF	D	Not interfering with the body builder interface.
Withstand	vibrations	DF	M	
Withstand	temperatur	DF	N	High and low.

4.6. Requirements Specification

The requirement specification describes the features and functions the final concept requires as seen in Table 3.

Table 3: Requirements specification for new air cleaner.

Requirements Specification				
ID	**Category**	**Requirement**	**Priority**	**Source**
R1	Functional	Filter particles	Must	System function
R2	Functional	Allow air flow to the combustion engine and compressor	Must	System function
R3	Performance	The air cleaner shall have a dust holding capacity of 7000 g.	Must	Volvo
R4	Standard	Dust holding complying with ISO 5011 fine dust.	Must	ISO 5011
R5	Performance	Pressure drop with clean filter must be lower than 3 kPa.	Must	Volvo
R6	Performance	Maximum static pressure drop of 5,5 kPa across the whole system with clean filter.	Must	Volvo
R7	Performance	Maximum pressure drop of 5,5 kPa with full filter	Must	Volvo
R8	Geometrical	Air cleaner fitting within body builder interface GIC043 for short cab and ICE *(see Appendix A)*.	Could	Volvo
R9	Geometrical	Compatible with turbo intake	Must	System function
R10	Geometrical	Compatible with current air inlet	Must	System function
R11	Sustainability	Avoid using PFAS-substances	Should	Volvo
R12	Sustainability	All materials shall be suitable for recycling.	Should	Volvo
R13	Sustainability	Minimize usage of toxic materials and declare if used.	Must	Volvo
R14	Sustainability	Use recycled polymers for all non-visible components.	Should	Volvo
R15	Sustainability	Use polymers with lower carbon footprint for visible components.	Must	Volvo
R16	Sustainability	Comply with “Volvo’s Red list”.	Must	Volvo
R17	Assembly	The new design shall not increase assembly time compared to the current.	Could	
R18	Assembly	The new design shall not require additional or more complex tooling during assembly than the current design does.	Could	
R19	Service	The new design shall not result in a service time exceeding the target service time of 6 minutes.	Could	Volvo

4.7. Idea Generation Phase

The idea generation phase resulted in a broad range of sub-solutions based on different functions and design aspects of the air cleaner. Ideas were generated across filter media, geometry, inlet configuration, placement as well as additional functional features. These concepts were later evaluated and combined into more complete solution concepts, forming the basis for further development and refinement.

4.7.1. Filter Media

- Paper-based filter media
- Nanofiber media
- Water-based filtration
- Oil-coated filter media
- Gradient media (coarse-to-fine structure)
- Cellulose composite media
- Multilayer media (coarse and fine filtration layers)
- Electrostatically charged media
- Hydrophobically treated filter media
- Combined inertial and fibrous filtration media

4.7.2. Geometry

- Cylindrical design
- Conical design
- Dual-cylinder configuration
- Spherical geometry
- Rectangular design
- Oval geometry (optimized for packaging constraints)
- Flat panel design
- Hexagonal structure
- Internal spiral configuration

4.7.3. Inlet Configuration

- Tangential inlet
- Normal inlet
- Wide or narrow inlet
- Multiple inlet ports
- Swirl generator upstream of inlet
- Adjustable inlet geometry
- Axial inlet
- Distribution plate downstream of inlet

4.7.4. Placement

- Current mounting position
- Integrated into the chassis
- Mounted behind the cab
- Engine-mounted
- Roof-mounted above the cab
- Externally side-mounted
- Under-chassis placement

4.7.5. Additional Features

- Scavenging outlet
- Two-stage air cleaner (integrated pre-separator followed by main filter stage)
- Active dust ejection system (ejector)
- Modular service package
- Bypass valve for blockage conditions
- Dust collection cup with drainage/emptying function

4.8. Morphological Matrix

Following the idea generation phase, the generated sub-solutions were organized into a Morphological matrix which can be seen in Table 4. The matrix was used to systematically combine different solution alternatives for each identified function, ensuring that the generation of multiple complete concepts were conducted, for more information about the method read section 3.5.

Table 4: Morphological matrix with different ideas for the defined categories.

Morphological Matrix					
Filter Media	**Geometry**	**Inlet Direction**	**Inlet Geometry**	**Placement**	**Additional Features**
Paper-based filter media	Cylindrical design	Tangential inlet	Wide inlet	Current mounting position	None
Nanofiber media	Conical design	Normal inlet	Narrow inlet	Integrated into chassis	Scavenging outlet
Liquid-based filtration	Dual- cylinder configura- tion	Axial inlet	Adjustable inlet	Behind the cab	Two-stage filtration
Oil-coated filter media	Spherical geometry	Multiple inlet ports	—	Engine- mounted	Active dust ejection system (ejector)
Gradient media (coarse-to- fine structure)	Rectangular geometry	Swirl inlet	—	Roof- mounted above the cab	Modular design
Cellulose composite media	Oval geometry	Distribution plate downstream of inlet	—	Externally side-mounted	Bypass valve under blockage conditions
Multilayer media (coarse and fine layers)	Flat panel structure	—	—	Under- chassis placement	Dust collection cup with drainage function
Electrostatically charged media	Sequential multi-panel configura- tion	—	—	—	—
Hydrophobically treated media	Hexagonal structure	—	—	—	—
Combined inertial and fibrous media	Internal spiral configura- tion	—	—	—	—

Generated Concepts

Based on the sub-solutions identified in the morphological matrix, ten different concepts were generated, each representing a unique combination of sub-solutions across the defined functions. These concepts provide a broad range of possible air cleaner designs for the development process. The combinations were selected based on the project group's considered judgment of which sub-solutions were considered most compatible and promising when combined.

Although additional combinations could have been generated to further minimize the risk of overlooking potential solutions, the selected concepts were considered a reasonable and relevant representation for continued evaluation. The complete overview of the generated concepts is presented in Table 5 below.

Table 5: Generated concepts from the morphological matrix.

Generated Concepts						
Concept	**Filter Media**	**Geometry**	**Inlet Direction**	**Inlet Geometry**	**Placement**	**Additional Features**
1	Paper- based filter media	Dual- cylinder configura-tion	Tangential inlet	Narrow inlet	Behind the cab	None
2	Gradient nanofiber media	Cylindrical design	Tangential inlet	Narrow inlet	Current mounting position	None
3	Cellulose composite media	Oval geometry	Tangential inlet	Wide inlet	Current mounting position	Scavenging outlet
4	Multilayer media	Sequential multi-panel configura-tion	Normal inlet	Wide inlet	Behind the cab	Modular design
5	Oil-coated filter media	Spherical geometry	Multiple inlet ports	Narrow inlet	Current mounting position	None
6	Liquid- based filtration	Conical design	Axial inlet	Narrow inlet	Behind the cab	None
7	Gradient nanofiber media	Dual- cylinder configura-tion	Tangential inlet	Narrow inlet	Under- chassis placement	Scavenging outlet
8	Gradient nanofiber media	Dual- cylinder configura-tion	Tangential inlet	Narrow inlet	Current mounting position	Dust collection cup with drainage function
9	Cellulose composite media	Cylindrical design	Tangential inlet	Wide inlet	Current mounting position	None
10	Paper-based filter media	Sequential multi-panel configura-tion	Normal inlet	Wide inlet	Externally side- mounted	Active dust ejection system (ejector)

4.9. Pugh Matrix

The Pugh matrix, seen in Table 6 shows how the ten concepts generated in the Morphological matrix performed compared to the reference solution, which is the currently used air cleaner in Volvo trucks. The concepts were assessed using criteria based on the technical requirements, which made it possible to identify differences between the concepts and highlight the most promising ones for further development. The method is presented in greater detail in section 3.6.

Table 6: Concepts evaluated with a Pugh matrix.

Pugh Matrix												
Criterias	**Solutions**	**Ref.**	**Nr. 1**	**Nr. 2**	**Nr.3**	**Nr. 4**	**Nr. 5**	**Nr. 6**	**Nr. 7**	**Nr. 8**	**Nr. 9**	**Nr. 10**
Dust holding capacity			+	+	+	+	+	+	+	+	+	+
Complexity			-	0	-	-	-	-	-	-	0	-
Volume			-	-	-	-	-	-	-	-	-	-
Pressure drop			0	+	-	-	+	-	-	+	0	-
Efficiency			+	+	+	+	+	-	+	+	+	+
Environmental impact			+	+	+	0	+	+	+	0	+	+
Serviceability			-	0	-	+	-	-	+	+	0	-
Sum		0	-1	+3	-1	0	+1	-3	+1	+2	+2	-2

Solutions 2, 5, 7, 8, and 9 received the highest scores in the Pugh matrix and were therefore selected for further evaluation in the Kesselring matrix.

4.10. Kesselring Matrix

The Kesselring matrix evaluates the five highest-ranked concepts from the Pugh matrix by scoring them based on the relative importance of the requirements. The results of the Kesselring matrix indicated that Concept 9 was the most optimal solution based on the overall score. The full matrix and ranking is presented in Table 7. More information about the method can be found in section 3.7.

Table 7: The scores show top 1-5 based on the ratings to each criteria.

Criteria		Ideal		Nr. 2		Nr. 5		Nr. 7		Nr. 8		Nr. 9	
	Weight	Score 1-5	Result	Score 1-5	Result	Score 1-5	Result	Score 1-5	Result	Score 1-5	Result	Score 1-5	Result
Dust holding capacity	**0,3**	5	1,5	4	1,2	3	0,9	5	1,5	5	1,5	4	1,2
Uniform dust collection	**0,15**	5	0,75	4	0,6	1	0,15	3	0,45	3	0,45	5	0,75
Complexity	**0,05**	5	0,25	5	0,25	3	0,15	2	0,1	3	0,15	5	0,25
Volume	**0,05**	5	0,25	4	0,2	3	0,15	2	0,1	2	0,1	4	0,2
Pressure drop	**0,15**	5	0,75	5	0,75	4	0,6	3	0,45	3	0,45	5	0,75
Filter efficiency	**0,1**	5	0,5	5	0,5	4	0,4	5	0,5	5	0,5	4	0,4
Environmental impact	**0,1**	5	0,5	5	0,5	4	0,4	3	0,3	4	0,4	5	0,5
Serviceability	**0,1**	5	0,5	5	0,5	4	0,4	3	0,3	3	0,3	5	0,5
Sum	(=1)		5	37	4,5	26	3,15	26	3,7	28	3,85	37	4,55
Ranking				2		5		4		3		1	

4.11. Further Development of the Top Three Concepts

To further develop the final concept, the three highest-ranked concepts from the Kesselring matrix were selected for refinement. These concepts were analyzed in greater detail to further explore their technical potential and suitability for the intended application. The result of this analysis is presented in this section.

4.11.1. Concept 9

Concept 9 uses a filter media referred to as cellulose+. The overall air cleaner design is based on a similar structural configuration to those currently used in existing truck applications. However, by replacing conventional cellulose media with cellulose+, the filtration performance is improved by 25%

The air cleaner has a cylindrical design with a wide tangential inlet, as seen in Figure 11. This inlet configuration is intended to distribute the airflow evenly across the filter surface, ensuring full utilization of the filter area. This reduces the risk of localized dust accumulation and promotes more uniform filter loading before dust cake formation occurs.

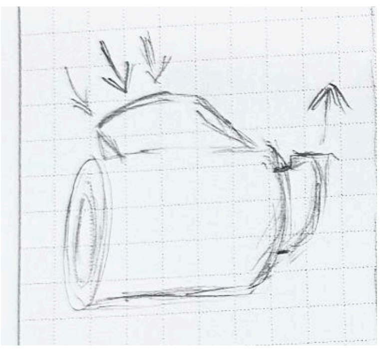

Figure 11: *Pen sketch of concept 9. Source: Own picture.*

4.11.2. Concept 2

Concept 2 is also based on a cylindrical air cleaner design with a tangential air inlet, although the inlet is narrower compared to Concept 9, this is visualized in Figure 12. The filter media consists of a non-woven gradient structure with a nanofiber coating.

This filter media captures particles throughout its depth, allowing higher dust holding capacity without rapid surface dust cake formation. Larger particles are retained near the outer surface, while smaller particles are captured deeper within the filter structure. The nanofiber coating on the inner filter layer improves the filtration efficiency for smaller dust particles and contributes to enhanced particle separation performance.

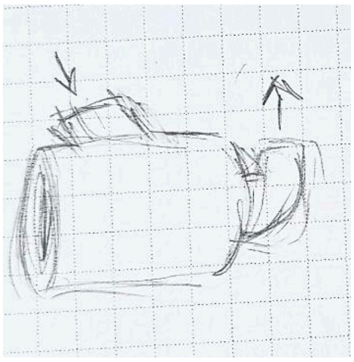

Figure 12: *Pen sketch of concept 2. Source: Own picture.*

4.11.3. Concept 8

Concept 8 is based on a dual air cleaner design, consisting of two filter elements. The filter media is the same as in Concept 2, a non-woven gradient structure with a nanofiber coating.

The air enters through a tangential inlet and is distributed between the two filter elements. The dual-filter configuration increases the available filtration area while maintaining a compact packaging volume. This allows greater dust holding capacity within a limited installation space. During service, both filter elements are replaced simultaneously, as dust loading is expected to be evenly distributed between them. A drawback of this concept is its increased design complexity, as two filter elements must be replaced during service. This results in higher replacement part requirements and increased material waste compared to a single-element solution.The concept also includes a dust collection cup with an active dust ejection function, which periodically removes collected dust to extend service life. However, this feature introduces increased system complexity, potential pressure losses, and higher manufacturing costs, making the concept more demanding to implement in this application. Concept 8 is illustrated in Figure 13.

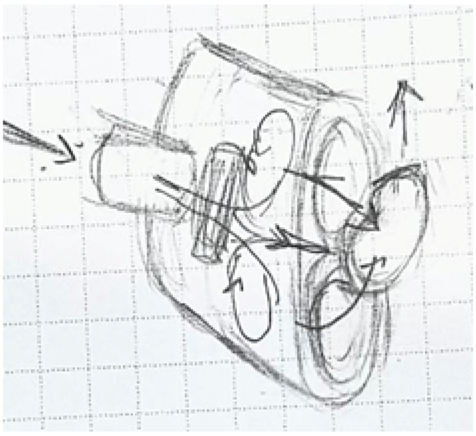

Figure 13: *Pen sketch of concept 8. Source: Own picture.*

4.12. Combining the Concepts

To further iterate the concept development, key features from the three highest-ranked concepts, Concept 9, Concept 2, and Concept 8, were combined. The purpose of this step was to explore new design solutions by merging the most promising characteristics from each concept. This resulted in two new concepts, referred to as Concept X and Concept Y.

4.12.1. Concept X

Concept X is a dual air cleaner system equipped with a gradient, nano-coated filter media. The design is based on a dual cyclone configuration inspired by Concept 8, enabling an increased filter area within a compact volume.

The inlet is tangential and designed with a width corresponding to the overall air cleaner diameter, which is visualized in Figure 14. This ensures a steady airflow distribution across the filter surface, promoting even dust loading and efficient utilization of the entire filter area. The filter media combines gradient depth filtration with a nano coating to improve particle capture efficiency across different dust sizes.

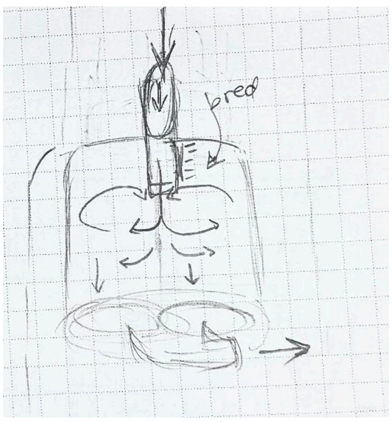

Figure 14: *Pen sketch of concept X. Source: Own picture.*

4.12.2. Concept Y

Concept Y also has gradient, nano-coated filter media, incorporating the same filtration principles as Concept X and Concept 2. The inlet is tangential and designed to match the full width of the air cleaner, as seen in Figure 15, to achieve an even airflow distribution and optimized dust capture across the filter surface.

In contrast to Concept X, Concept Y is based on a single large cylindrical design rather than a dual cyclone configuration. The system is scaled to accommodate a dust capacity of 7000 g, enabling extended service intervals while maintaining a simpler structural design with fewer components.

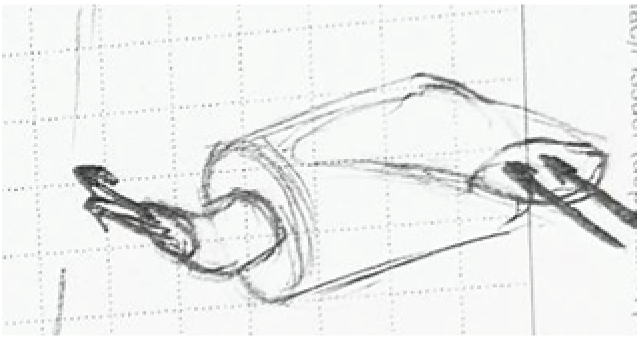

Figure 15: *Pen sketch of concept Y. Source: Own picture.*

4.13. Additional Concepts for a Broader Perspective

With the aim of broadening the design space and ensuring that no potential concepts were overlooked, an additional iteration of the idea generation phase was conducted. This step was carried out to introduce a wider variation of solutions, as the previous concepts showed some similarities in both structure and function. As a result, four additional concepts were generated to further explore as alternative design solutions..

4.13.1. Concept Z

Concept Z consists of several rectangular filter elements arranged in series within a box-shaped air cleaner housing. The concept is partly inspired by filter solutions used in electric Volvo trucks; however, due to the higher air flow requirements and increased dust holding capacity needed for combustion engine applications, the filter surface area is significantly increased. This is achieved by enlarging the individual filter surfaces and stacking multiple elements in order to meet the required dust holding capacity.

A potential drawback of this concept is the increased risk of high pressure drop, as the airflow must pass through multiple filter stages with relatively high resistance. A pen sketch of concept Z can be seen in Figure 16.

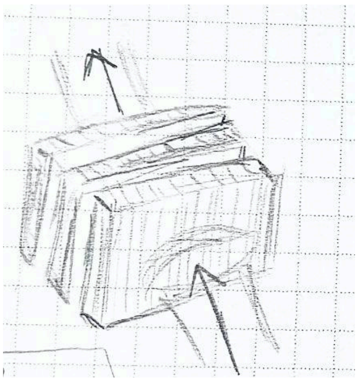

Figure 16: *Pen sketch of concept Z. Source: Own picture.*

4.13.2. Concept W

Concept W is based on a tapered cylindrical air cleaner mounted directly underneath the cab. The design eliminates the need for a separate air intake housing, which reduces both material usage and installation space requirements. Concept W is visualized in Figure 17.

However, a key disadvantage of this configuration is that air drawn from a lower position close to the road usually contains a more concentrated dust compared to air supplied via an intake snorkel upon the cab. This may negatively affect filter loading and overall system performance.

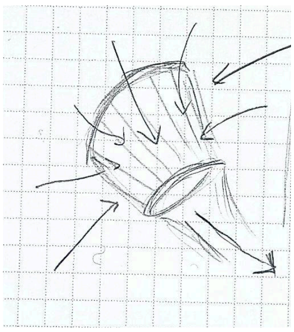

Figure 17: *Pen sketch of concept W. Source: Own picture.*

4.13.3. Concept α

Concept α**.** seen in Figure 18, consists of two concentric cylindrical filters, where a smaller inner cylinder is positioned inside a larger outer cylinder. This configuration allows for two separate filtration surfaces within a compact volume, effectively increasing the total dust collection area.

Although this design improves packaging efficiency, the use of two surface-loading filters may reduce overall dust holding efficiency compared to deeper filtration structures, particularly under high dust load conditions.

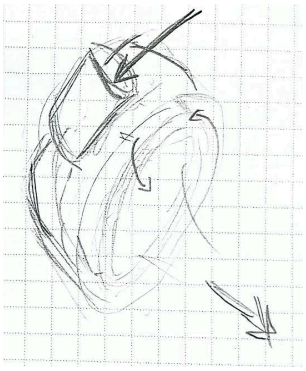

Figure 18: *Pen sketch of concept* α. *Source: Own picture.*

4.13.4. Concept β

Concept β is visually similar to Concept Y from the previous set, featuring a cylindrical air cleaner with a tangential and wide inlet for uniform airflow distribution. The key difference lies in the filter media design, which incorporates a significantly wider pleat structure compared to earlier concepts. This is visualized in Figure 19.

The intention of this design is to increase filter depth and thereby improve dust holding capacity before reaching end-of-life. However, the increased pleat depth may also contribute to a higher pressure drop as dust accumulates, increasing flow resistance over time. Additionally, the relatively small outlet area further contributes to an overall increase in pressure drop within the system.

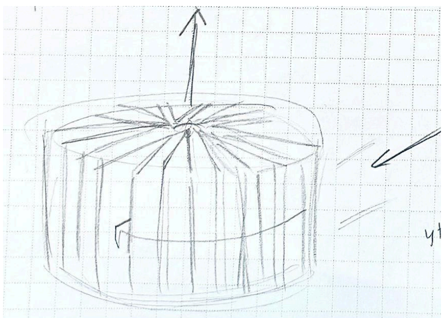

Figure 19: *Pen sketch of concept* β. *Source: Own picture.*

4.14. Interviews with Filter Media Suppliers

Following the research findings as well as the concept generation phase, the filter media Micrograde N was identified as a promising solution due to its potential to optimize dust holding capacity while maintaining a sufficiently compact filter volume to meet the packaging limitations in the truck. In order to get a deeper understanding of the filter media Micrograde N and determine whether it is applicable in a heavy-duty truck an interview with the suppliers of the filter media was held, see Appendix 3. This section summarizes the key learnings taken from the interview that the concept choice later is based on.

4.14.1. Micrograde N

The suppliers explained that the filter media Micrograde N primarily is developed for passenger car applications, where operating conditions differ significantly from heavy-duty vehicles. Passenger cars typically use smaller air cleaners due to their reduced scale and lower dust holding requirements. This leads to a smaller filter surface area, which in turn results in a significantly higher face velocity through the filter media.

The higher face velocity in passenger cars is beneficial for Micrograde N, as the material is designed to capture particles throughout its depth rather than only on the surface. However, in heavy-duty applications, the larger filter area leads to a lower face velocity. Under these conditions, particles are not efficiently transported into the depth of the media, which results in dust primarily accumulating on the surface instead of being distributed throughout the filter structure. Consequently, the intended benefit of depth filtration is not fully utilized in heavy-duty truck applications.

The suppliers explained that the performance benefits observed with Micrograde N in passenger car applications cannot be expected to translate to heavy-duty truck applications. Due to the lower face velocity and different operating conditions in larger air cleaners, the material does not operate within its intended performance range. As a result, the key advantages associated with depth filtration are not effectively utilized and therefore the suppliers do not recommend Micrograde N as a filter media for this project.

4.14.2. Cellulose +

Instead, the suppliers recommended a high-performance cellulose-based filter media, referred to as Cellulose+, which is part of their heavy-duty product offering. Compared to conventional cellulose media, Cellulose+ provides approximately 25% higher dust holding capacity at the same filter volume.

The material consists of a hybrid fiber structure combining cellulose fibers and synthetic fibers. Unlike Micrograde N, this media does not require high face velocity to achieve optimal performance, making it more suitable for applications with larger filter areas and lower airflow velocities, such as heavy-duty trucks.

To achieve a maximized dust holding capacity per unit volume, a large effective filter surface area is required. This is achieved through filter geometry design and pleat configuration, where a standard pleat height of 60 mm is used to increase the available filtration area within the given packaging constraints. The suppliers made it clear this solution would perform better than Micrograde N for a heavy-duty application.

4.15. Final Choice of Filter Media

Based on the supplier interview and their expertise in automotive filtration systems, Cellulose+ was selected as the final filter media for the concept development. The main reason for this selection is its suitability for heavy-duty operating conditions, where Micrograde N was found to be less appropriate due to its dependency on higher face velocities.

Although Cellulose+ does not utilize depth filtration like Micrograde N, it still provides a significant improvement in dust holding capacity compared to conventional cellulose media. This allows for a reduction in required filter volume while still meeting the target dust capacity of 7000 g.

Overall, Cellulose+ offers a balanced combination of performance, DHC and suitability for heavy-duty applications, making it the most appropriate choice for the final concept

4.16. Cylinder Housing

After the selection of Cellulose+ as filter media, the decision regarding the geometry of the air cleaner was made. Since it was established that the required filter volume could be reduced compared to the volume needed when conventional cellulose is used, the decision to use a cylindrical air cleaner was taken. The expectation was that the cylindrical volume required to hold 7000 g of dust with Cellulose+ would fit within the packaging limitations of the truck. This was later verified through dimensional calculations presented in the following section, see section 4.17. Calculations of dimensions for the filter, confirming that the cylindrical air cleaner fits within the available space.

The cylindrical design was chosen since it is one of the least complex solutions among the considered alternatives. By maintaining a well-established and simple geometry, the design avoids unnecessary complexity and reduces the number of required components. From a service perspective it is also beneficial since it is only one main filter that has to be replaced during maintenance. A safety filter is still included within the housing, but this does not have to be replaced during regular service intervals.

In addition to the cylindrical geometry, a broader tangential air inlet was selected. This design ensures an even airflow distribution across the filter surface, supporting even dust loading and efficient utilization of the full filter area, while reducing the risk of localized clogging.

Overall, these design choices are based on a prioritization of simplicity, serviceability and compatibility with the existing system architecture.

4.17. Calculations of Dimensions for the Filter

Based on the selected filter media Cellulose+, the following section describes the dimensioning of the air cleaner. The calculation of the filter dimensions is based on the current air cleaner geometry, as the new concept is intended to maintain a similar overall design and packaging layout.

Since the new concept is required to achieve an increased dust holding capacity, with additional 4000 g of dust compared to the current system, a larger effective filter volume is initially required. However, due to the improved performance characteristics of Cellulose+, including a thinner media structure and more efficient pleat utilization, the required filter volume can be reduced by approximately 25% compared to the current filter media. These calculations are based on a filter pleat height of 60 mm, as recommended by the filter suppliers in order to avoid excessive pressure drop.

A key factor influencing the final geometry is the available packaging space within the truck. This includes constraints related to surrounding components such as the cab, engine, and interfaces defined by bodybuilder requirements. These spatial limitations have a significant impact on the final design of the filter housing and overall air cleaner geometry.

4.17.1. Calculation of the Current Filter Volume

In order to determine the required volume of the new filter cylinder in order for it to hold 7000 g of dust, the filter volume of today's filter was calculated based on these parameters.

- Outside diameter D = 326 mm
- Pleat height b = 58 mm
- Active height H = 350 mm
- Number of pleats i_p = 388
- Filter surface A_e = 13.72 m^2

Since the filter can be seen as a hollow cylinder, the total active filter volume is determined by calculating the volume of the outer diameter of the cylinder and subtracting that with the hollow volume of the inner cylinder, which diameter is 60 mm less, determined by the pleat height of the filter, see Figure 20 below.

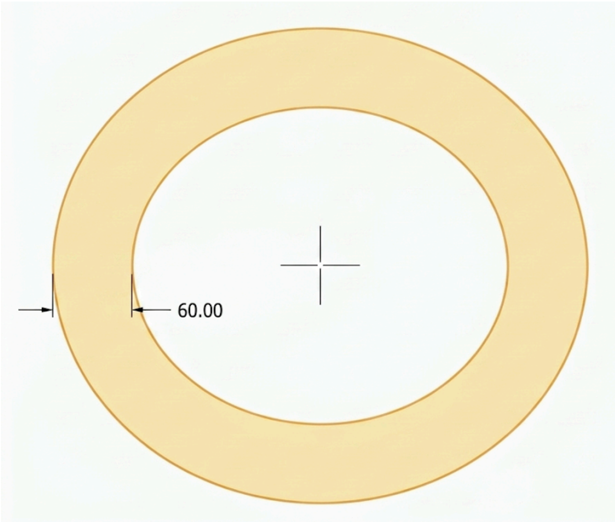

Figure 20: *Cross-section of primary filter. Source: Own picture.*

The outer radius is calculated from the outer diameter:

- $R_o = D / 2 = 326 / 2 = 163$ mm

The inner radius is determined by subtracting the pleat height from the outer radius:

- $R_i = R_o - b = 163 - 58 = 105$ mm

The volume of the outer cylinder is then calculated as:

- $V_o = \pi \times R_o^2 \times H$
- $V_o = \pi \times 163^2 \times 350 = \pi \times 9{,}299{,}150 = 29{,}214{,}150$ mm³

The volume of the inner hollow cylinder is:

- $V_i = \pi \times R_i^2 \times H$
- $V_i = \pi \times 105^2 \times 350 = \pi \times 3{,}858{,}750 = 12{,}122{,}624$ mm³

The active filter volume is obtained by subtracting the inner volume from the outer volume:

- $V_f = V_o - V_i$
- $V_f = 29{,}214{,}150 - 12{,}122{,}624 = 17{,}091{,}526$ mm³

To express the result in liters:

- $V_f = 17{,}091{,}526 / 1{,}000{,}000 = 17.09$ L

The calculated active filter volume is therefore 17.09 liters in today's solution with conventional cellulose as filter media.

4.17.2. Calculation of the New Filter Volume

The proportional increase in volume to have a DHC of 7000 g, is calculated as:

- $V_{new,conventional\text{-}cellulose} = V_{current,conventional\text{-}cellulose} \times (7000 / 3000) = 17.09 \times (7000 / 3000) = 39.88$ L

However, since the selected filter media Cellulose+ provides approximately 25% higher DHC compared to conventional cellulose media, the required filter volume can be reduced by 25%. The required filter volume is therefore:

- $V_{new,cellulose+} = V_{new,conventional\text{-}cellulose} \times 0.75 = 39.88 \times 0.75 = 29.91$ L

The required active filter volume for the new concept is therefore 29.91 liters. This confirms that the improved performance of Cellulose+ significantly reduces the required filter volume compared to what would otherwise be needed to achieve a dust holding capacity of 7000 g with conventional cellulose media.

4.17.3. Selection of Geometry for the New Filter

Even though Cellulose+ requires less volume compared to conventional cellulose the total active filter volume that is needed is still increased, since the dust holding capacity has been increased. The geometry of the new air cleaner is not able to be the exact same proportions as the old one, scaled up since it would clash with components or constraints in the packaging of the truck. The choice of geometry for the new air cleaner is therefore determined by aspects such as tolerances in the truck as minimizing the pressure drop.

The first limitation that is a big determination of the geometry of the air cleaner are the tolerances in the packaging of the truck. The tolerances for space between the air cleaner and the surrounding components depend on how the air cleaner is mounted. The required space between the air cleaner and the cab, in z-led, is 50 mm (personal communication, 2026), see Figure 21. This is to make sure no collisions happen when the cab moves up and down when the truck is driven. Another factor resulting in this tolerance is the air suspension which lowers the cab when the air is emptied.

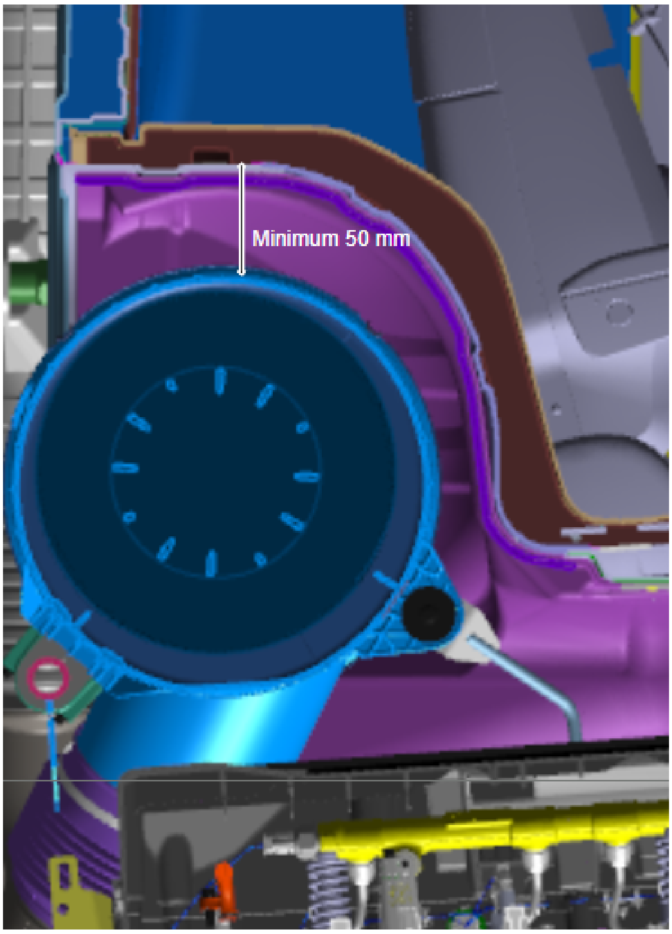

Figure 21: *Minimum space tolerance between the air cleaner and the cab. Source: Own picture.*

In today's solution the space tolerance in z-led to the engine is 25 mm due to vibrations and movements (personal communication, 2026). However, if the air cleaner is engine mounted rather than chassis mounted like today, the tolerance in z-led is decreased to 12 mm of space between the component and the engine. This means an allowance of a larger air cleaner. The tolerance of space to remaining components surrounding the air cleaner is 25 mm in x- and y-led. This is also to eliminate the risk of collision during vibrations and movements in the truck when driven.

The last packaging tolerance that had to be taken into consideration when designing the air cleaner is the body builder interface. It is shown in Figure 22 below. This is where the trailer would be mounted. Volvo requested that this interface should be taken into consideration if possible, but the requirement of dust holding capacity as well as remaining tolerance requirement were superior and had to be achieved. If the body builder interface interferes with the air cleaner the trailer has to be further back, but this is a compromise Volvo is willing to make in case the rest of the requirements are achieved.

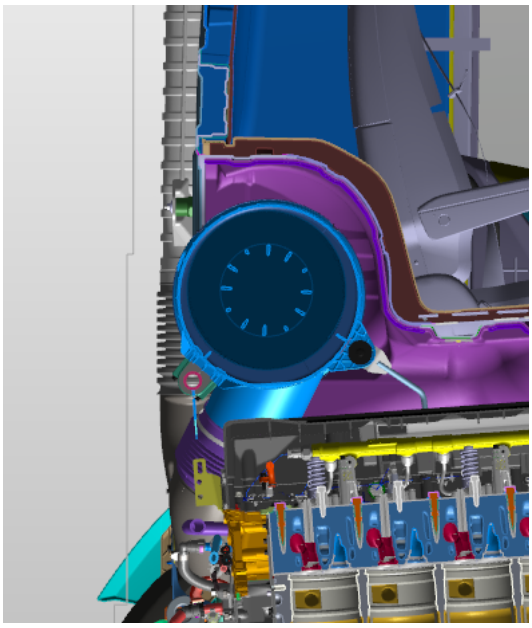

Figure 22: *Cross-section of old air clear with body builder interface (black line to the left). Source: Own picture.*

For a steady air flow and even dust spread throughout the filter the geometry of the air cleaner benefits from being as circular as possible with a big radius. The air inlet is tangential to the filter cylinder to avoid the dust hitting the filter media directly at one spot near the inlet causing it to clog with dust faster than the rest of the filter. The space between the air filter housing and the filter cylinder should also be big enough for the air to flow steady without too much pressure building up. Since all the air flows from the inlet there is more space to the air cleaner here to allow a smooth inlet flow, see Figure 23 below.

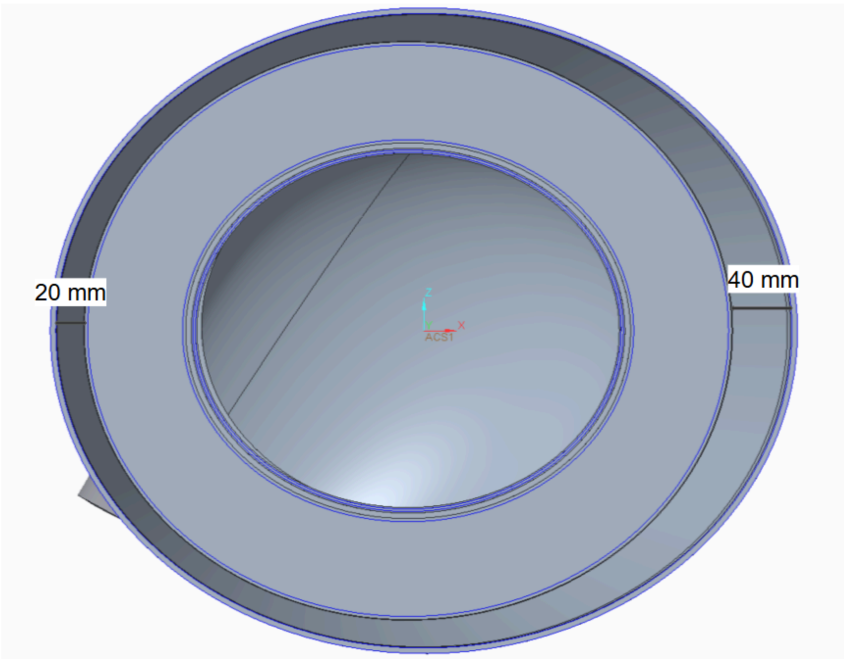

Figure 23: *Cross-section of offset between housing and filter. Source: Own picture.*

4.17.4. Determining Factors for Dimensions

After establishing the required filter volume and considering the packaging constraints within the truck, it became clear that the new air cleaner required an elliptical cross-section in order to avoid interference with surrounding components. This is because the geometry allows the air cleaner to be scaled further in width without clashing with the bodybuilder interface, while height expansion is more restricted due to the required tolerances to both the cab and the engine.

The decision to use an engine-mounted configuration was also made at this stage, as it allows the air cleaner to utilize more of the available installation space by reducing the required clearance to the engine. In addition, an engine-mounted solution has been requested by Volvo's assembly line, as it simplifies the assembly process and improves manufacturing efficiency.

The maximum allowable height of the ellipse as well as the active height of the filter cylinder were determined through measurements taken in the cab and were used as fixed constraints when defining the remaining dimensions of the filter cylinder, together with the previously established required filter volume. The pleat height was also fixed at 60 mm, based on the recommendation from the filter suppliers, as exceeding this value could result in increased pressure drop.

- Outside diameter 1: D_1 (height of ellipse) = 362 mm
- Pleat height b = 60 mm
- Active Height H = 491 mm

4.17.5. Calculation of Remaining Filter Dimensions

The remaining measurement to calculate is the width of the ellipse:

Diameter 2 (height of ellipse): width of ellipse = D_2

We first determine the required cross-sectional area from the given volume:

- $A_{cross\text{-}section} = V_{new,cellulose+} / H$
- $A_{cross\text{-}section} = 29{,}910{,}000 / 491$
- $A_{cross\text{-}section} = 60{,}874 \text{ mm}^2$

For an elliptical cross-section the area is:

- $A_{cross\text{-}section} = \pi \times (D_{1,outer} \times D_{2,outer} - D_{1,inner} \times D_{2,inner})$
- $A_{cross\text{-}section} / \pi = (D_{1,outer} \times D_{2,outer} - D_{1,inner} \times D_{2,inner}) / 4$
- $(60{,}874 / \pi) \times 4 = (D_{1,outer} \times D_{2,outer} - D_{1,inner} \times D_{2,inner})$
- $77{,}508 = D_{1,outer} \times D_{2,outer} - D_{1,inner} \times D_{2,inner}$

Pleat height b = 60 mm

- $D_{1,outer} = 362$ mm
- $D_{1,inner} = 242$ mm
- $D_{2,outer} = D_2$
- $D_{2,inner} = D_2 - 120$

Inserted to the calculation:

- $77{,}508 = (362 \times D_2) - (242 \times (D_2 - 120))$
- $77{,}508 = 362 \times D_2 - 242 \times D_2 + 29{,}040$
- $77{,}508 = 120 \times D_2 + 29{,}040$

Solve for D_2:

- $77{,}508 - 29{,}040 = 120 \times D_2$
- $48{,}468 = 120 \times D_2$
- $D_2 = 405$ mm

The filter media width must be 405 mm in order to satisfy all constraints and achieve a DHC of 7000 g.

4.18. Final Concept

Summarizing the final concept, the design consists of an engine-mounted air cleaner using Cellulose+ as filter media. See the final design in Figure 24 below.

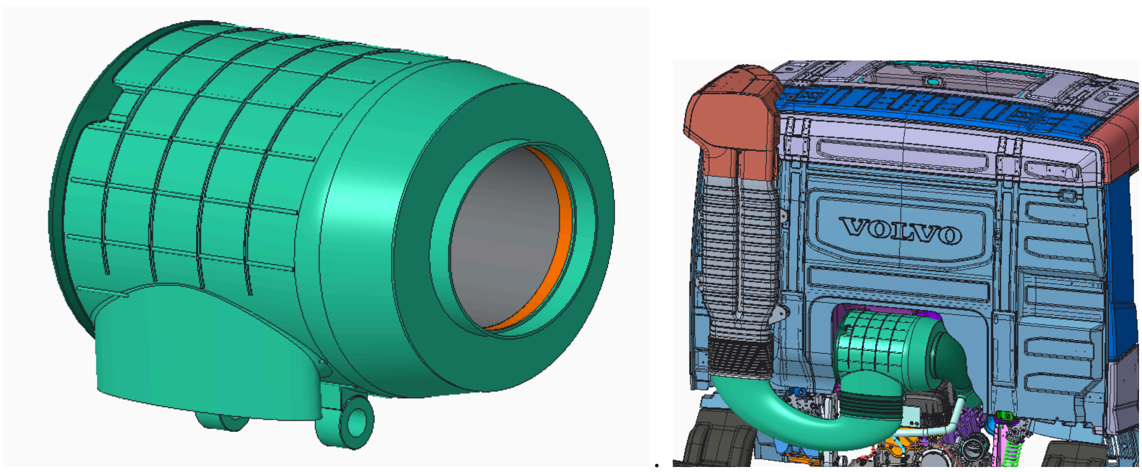

Figure 24: *The new air cleaner shown as a module and in the truck. Source: Own picture.*

4.18.1. Geometrical Dimensions of the Filter Cylinder

- Outside diameter 1: D_1 (height of ellipse) = 362 mm
- Outside diameter 2: D_2 (width of ellipse) = 405 mm
- Pleat height b = 60 mm
- Active Height H = 491 mm

The dimensions of the filter are shown in the cross-section in Figure 25 below.

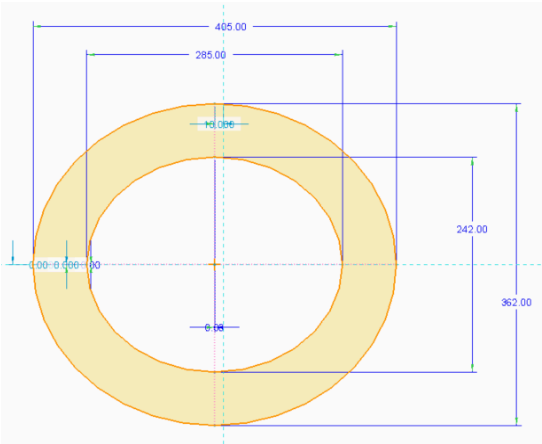

Figure 25: *Cross-section of filter. Source: Own picture.*

4.18.2. Geometrical Dimensions of the Housing

- $D_{housing,1}$ (height of ellipse) = 409 mm
- $D_{housing,2}$ (width of ellipse) = 472
- Wall thickness t = 3.5 mm
- Length L = 518 mm

The dimensions of the housing are shown in the cross-section in Figure 26 below.

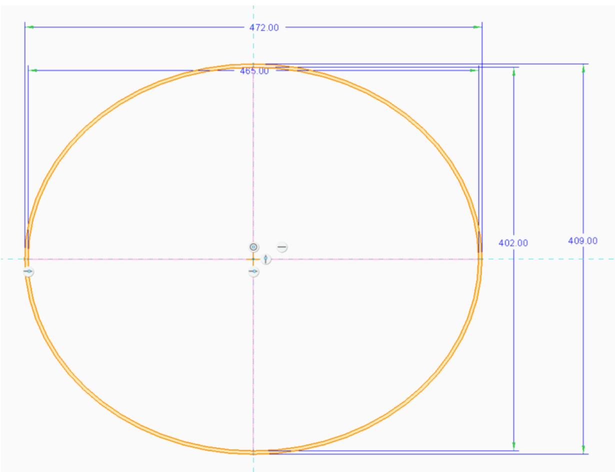

Figure 26: *Cross-section of filter housing. Source: Own picture.*

These dimensions ensure a minimum clearance of 20 mm between the filter cylinder and the housing. This gap is necessary to allow sufficient airflow between the components and to prevent excessive pressure losses.

The filter element is also positioned slightly off-center within the housing. This design choice improves airflow distribution, providing increased space at the inlet where the incoming air velocity is highest and where pressure build-up would otherwise be most critical.

4.18.3. Ribs

The decision to include ribs was also made in order to reinforce the structure of the housing making it resilient to vibrations during operation.

4.18.4. Inlet

The inlet is designed tangentially to the filter cylinder and has been widened to ensure a more uniform airflow distribution across the filter surface. This promotes even dust loading and supports efficient utilization of the entire filter area.

4.18.5. Outlet

The outlet retains a similar concept to the current design, directing the cleaned air toward the turbocharger. It has been slightly adapted to fit the new air cleaner geometry, but otherwise follows the same functional principle.

4.19. DFA

When the new concept of air cleaner has been developed, design for assembly (DFA) has been taken into consideration. The assembly at Volvo Trucks takes place within a part of the company called Volvo Group Operations (GTO). Here, the main assembly line is located, where modules are assembled on a continuously moving line (personal communication, 2026). Some assemblies are larger and some are smaller, but the goal within GTO is to make the main assembly line as efficient as possible while maintaining good ergonomics for the operators.

By developing a larger air cleaner, this results in heavier and more bulky parts to assemble. However, this is not a major issue due to the efficient tools available at the assembly line. It is beneficial that the air cleaner is now engine-mounted, since it can then be assembled to the engine before the actual main assembly, making the process at the main assembly line more time efficient. An example of how the air cleaner could be mounted on the engine can be seen below in Figure 27.

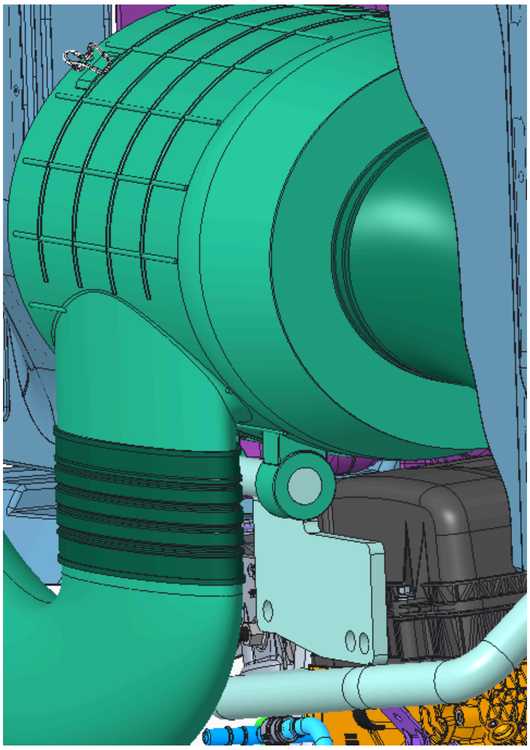

Figure 27: *Visualization of how the air cleaner could be mounted with a bracket on the engine. Source: Own picture.*

4.20. DFM

From a design for manufacturing (DFM) perspective, the design has been developed with consideration for plastic injection molding. The inlet geometry has been kept straight, rather than using a curved routing that would improve packaging integration within the truck.

Injection moulding was selected as the baseline manufacturing process due to its capability to produce high-precision components with tight tolerances and well defined interfaces (McClements, 2022). Blow molding is primarily suitable for hollow components with more continuous and organic geometries, such as ducts or containers, rather than geometries requiring precise functional interfaces.

A uniform wall thickness has been maintained throughout the housing in order to reduce the risk of sink marks, warping, and other typical defects associated with injection molding processes (McClements, 2022) .

Tool-related features such as draft angles were not included in the CAD model, as these are typically defined and optimized during tooling design by the supplier, as advised by a specialist air intake engineer.

The interface section between the air intake and the air cleaner housing has a geometry that is compatible with blow molding due to its smooth, continuous cross-sectional shape (McClements, 2022).

5. Analysis and Discussion

The results demonstrate that the dust holding capacity of the air cleaner can be increased significantly, successfully reaching the targeted 7000 g. This was achieved while maintaining the same positioning in the truck and ensuring compatibility with body builder interfaces and surrounding structures on both the cab and chassis, a significant constraint that shaped several of the design decisions discussed in the following sections. A comparison of the old and new package can be seen in Figure 28 below.

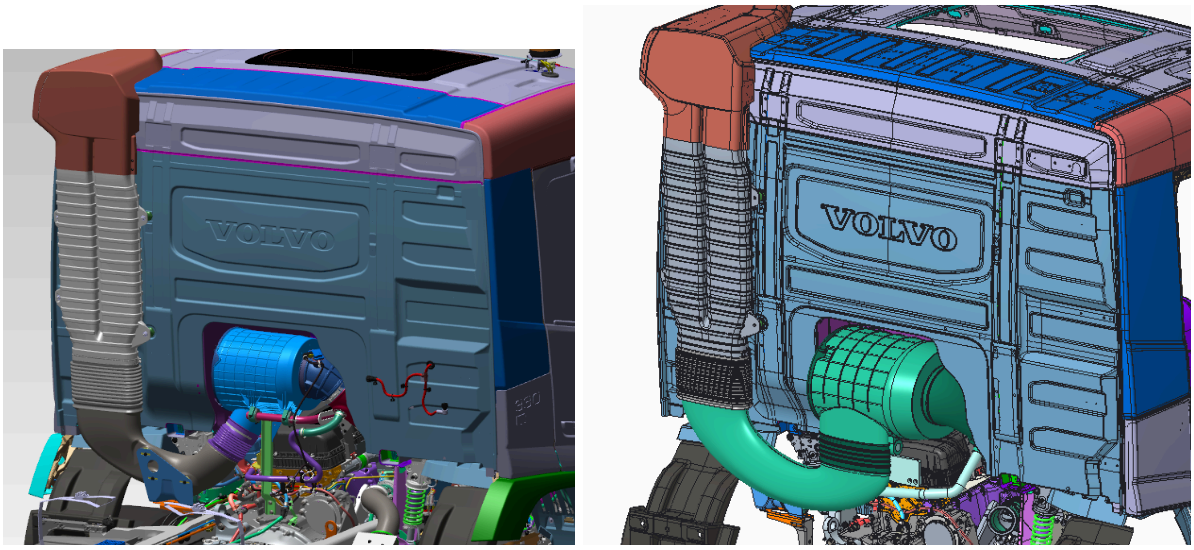

Figure 28: *Comparison in size between old air cleaner (left) and newly developed air cleaner (right). Source: Own picture.*

The substantial increase in dust holding capacity directly extends the operational intervals between filter services, reducing the need for unplanned downtime. This is of considerable practical importance in applications where constant vehicle operation is critical, such as open pit mining and large scale construction. In these environments, heavy-duty trucks are often exposed to air heavily contaminated with dust particles. A clogged air filter results in increased pressure drop and increased fuel consumption, leading to higher operational costs. In addition, downtime related to filter replacement contributes to reduced productivity and increased maintenance costs.

The developed solution reduces these issues by providing more than double the dust holding capacity of the reference design while still fulfilling the packaging and integration constraints of the vehicle, see Figure 29 for visualization of new air cleaner and body builder interface.

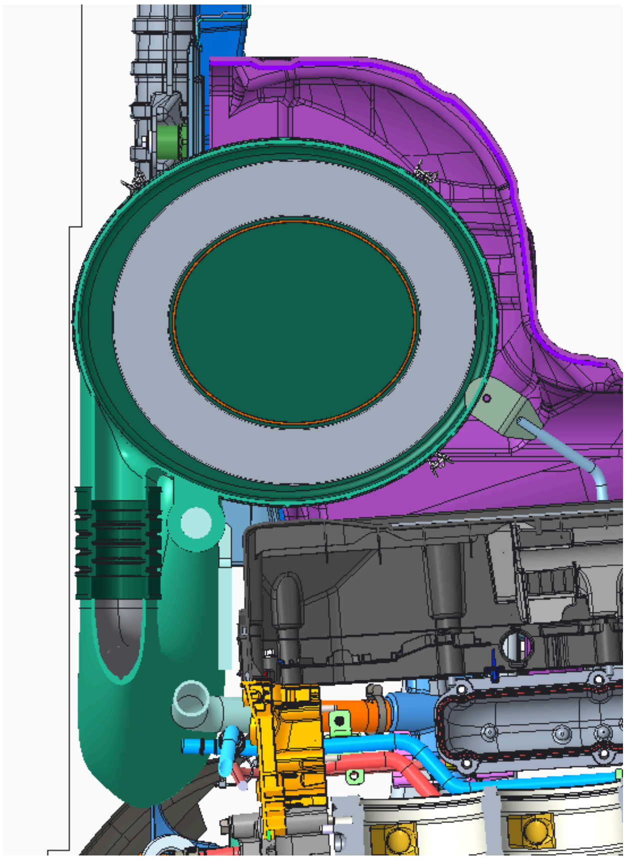

Figure 29: *Picture shows newly developed air cleaner together with body builder interface (black line on left side). Source: Own picture.*

Reaching the 7000 g target also strengthens competitiveness, as this level of performance has become increasingly important within the heavy-duty truck segment. The following sections discuss the key design choices, trade offs and technical factors that contributed to the achieved performance.

5.1. Performance Evaluation

The performance of the developed air cleaner can primarily be evaluated through its dust holding capacity followed by its pressure drop characteristics.

The dust holding capacity was validated through theoretical calculations based on the dimensions and performance of the current reference filter using the existing filter media. The volume of the current filter and its corresponding dust holding capacity of 3000 g were first determined. The filter size was then scaled to achieve the targeted dust holding capacity of 7000 g. Since the selected filter media allows for a higher filter surface area per unit volume, the required filter volume was multiplied by a factor of 0.75. Based on these calculations, a filter with suitable dimensions was designed to contain enough filter media to theoretically achieve the targeted dust holding capacity while still fitting within the available packaging space.

The pressure drop of the developed concept could not be validated experimentally within the timeframe of the project. Reliable validation would have required either a full scale prototype tested in Volvo Group's airflow test rig or a comprehensive Computational Fluid Dynamics (CFD) analysis. Neither alternative was possible within the available project timeframe, as prototype manufacturing would have required several weeks and the sufficient CFD resources were not available to us students during the project period. In addition, uncertainties regarding the airtightness of the CAD geometry remained due to the transition between surface modelling in Autodesk Alias and solid modelling in Creo Parametric.

Despite the lack of quantitative validation, there are several strong arguments that can be made suggesting that the developed air cleaner would likely result in a lower pressure drop compared to the current design.

One important factor is the increased overall size of the air cleaner housing, which allows the airflow to be distributed through a larger volume, thereby reducing flow resistance. The filter itself is also significantly larger, providing a greater filtration area. As the same airflow is distributed over a larger filter surface, the face velocity through the filter media is reduced compared to the reference design, which is expected to lower the pressure drop across the filter. Although certain airflow passages within the concept contain tighter bends than the reference design, these sections were compensated by larger cross-sectional areas in order to minimize their impact on the overall pressure drop.

To ensure that the pressure drop remains below the maximum allowable levels, a physical prototype should be manufactured and tested in Volvo Group's airflow test rig during future development of the concept. Testing would be necessary both to validate the performance of the proposed design and to identify potential areas requiring further optimization.

5.2. Filter Material Selection

The initially considered filter material had the potential to significantly increase the dust holding capacity compared to the selected alternative. According to supplier information, the material could provide approximately 30% higher dust holding capacity per installation volume compared to conventional cellulose filters. This improvement is achieved through depth loading, where dust is captured throughout the filter media rather than mainly on the surface, as is the case for standard cellulose-based filters.

However, following discussions with the supplier, it became clear that this type of material is primarily intended for passenger car applications, where the airflow velocity is sufficiently high to allow dust particles to penetrate deeper into the thicker filter media. In heavy-duty truck applications, the airflow velocity is generally lower, meaning that dust particles tend to accumulate closer to the filter surface rather than throughout the full depth of the media.

In the proposed concept, this effect is expected to be even greater due to the larger filter area, which further reduces the face velocity compared to conventional truck air cleaners. As a result, an approach focused on increasing the effective filter area was considered more suitable for improving dust holding capacity.

Because of this, a cellulose-based filter material was selected instead, in line with supplier recommendations for heavy-duty applications. The chosen material features a reduced thickness, which enables a higher number of pleats within the same installation volume. This allows for improved utilization of the available space and increased effective filter area.

Through optimization of the filter geometry and installation layout, the selected material still enables an estimated increase in dust holding capacity of approximately 25% compared to the reference filter. Although this is lower than the theoretical potential of the initially considered material, the final selection represents a more robust and application-suitable solution.

5.3. Key Design Decisions

One of the most important design decisions during the project was the use of an elliptical shape for both the filter element and the air cleaner housing. This decision was primarily driven by the limited installation space available beneath the cab and above the engine, where the current air cleaner is positioned.

A circular filter with the required diameter to achieve the targeted filter volume would have interfered with the underside of the cab. However, additional space was available in the lateral direction of the vehicle. By utilizing an elliptical geometry instead of a circular variant, the required filter volume could be achieved while still fitting within the available packaging space. Once suitable dimensions for the height and width of the filter had been established, the required filter length could be determined in order to achieve the target filter volume.

The dimensions of the air cleaner housing were primarily based on the filter geometry, although the surrounding installation space within the truck also had a major influence on the final design. Measurements performed on an existing air cleaner indicated that the spacing between the filter and the housing should be at least 20 mm, with larger spacing near the inlet region. These observations were implemented in the developed concept, where a clearance of approximately 40 mm was used for the area around the inlet. The intention was to improve airflow distribution around the filter and allow a greater amount of air to reach all sections of the filter surface more evenly. Due to the elliptical shape of both the filter and housing, the space in the corners were as low as 18 mm. This might have a negative impact on the pressure drop but increasing the whole housing would lead to interference with the surrounding noise shield. A decision to compromise pressure drop rather than installation margins was made.

The inlet was also designed with a more tangential flow direction in order to promote smoother airflow through the air cleaner housing. The intention behind this design choice was to improve airflow distribution around the entire filter surface and reduce the risk of dust accumulating mostly near the inlet region. By encouraging the airflow to circulate more evenly around the filter, utilization of the whole filter media could potentially be achieved, which may contribute to improved dust holding performance and reduced localized filter loading.

To accommodate the new air cleaner geometry, new inlet and outlet pipes were also developed. A redesigned pipe connecting the air cleaner to the air duct hose is required in order to match the updated inlet position and geometry of the developed concept. Similarly, a new outlet pipe connecting the air cleaner to the turbocharger was designed to fit the modified outlet location and packaging conditions. These components became important parts of the overall system integration and required careful consideration of routing, surrounding structures and airflow.

Another important design decision was to develop the concept as an engine mounted solution. One of the main reasons for this was to minimize the required clearance towards the engine in order to maximize the available space towards the cab floor, where a minimum clearance requirement of 50 mm had to be fulfilled. Based on recommendations from engineers involved in the project, the developed concept was positioned approximately 12 mm from the engine valve cover.

An engine mounted solution was also preferred from a manufacturing and assembly perspective. According to recommendations from the GTO department, mounting the air cleaner together with the engine simplifies the assembly process since the complete system can be installed before reaching the main assembly line.

Several design decisions regarding the inlet and outlet geometry were also influenced by the limited packaging space and the ambition to minimize pressure losses. Although certain airflow passages required tighter bends due to surrounding structures, larger cross-sectional areas were used in these regions to reduce flow resistance and compensate for the increased curvature. The design process therefore involved continuous trade offs between packaging constraints, airflow performance and integration requirements in order to achieve a feasible concept for the intended application.

5.4. Manufacturing, Assembly and Service

The manufacturing approach is kept close to the current solution, mainly because the used processes are well proven in similar applications. This reduces risk compared to introducing new methods that would require more validation and development.

From an assembly perspective, design for assembly has been considered in relation to the production system at Volvo Group Trucks Technology and the Volvo Group Operations (GTO) main assembly line. Larger components can increase handling effort, but this is manageable due to available lifting tools and established processes. An advantage is that the air cleaner is engine-mounted, which allows pre-assembly before reaching the main line and improves overall assembly efficiency.

From a service perspective, the existing maintenance procedure has been kept to avoid added complexity, although this also limits potential improvements in service ergonomics.

Overall, the design focuses on proven manufacturing and assembly methods to ensure robustness and integration within existing systems, rather than more optimized but less validated alternatives.

5.5. Cost Considerations

The developed air cleaner would likely result in a higher initial cost compared to the air cleaners currently in operation. This is partly due to the increased size of the system and the larger filter element, both of which require a greater amount of material. In addition, the selected material and the more complex geometry may contribute to increased manufacturing and supplier costs.

Another important factor is that this type of air cleaner is primarily intended for demanding environments with high concentrations of dust particles in the air. As a result, the solution is unlikely to be required for all heavy-duty truck applications, such as long distance highway transportation where the air conditions generally are better. Instead, the developed concept is more relevant for more extreme conditions such as mining operations and sugarcane fields, where dust exposure is significantly higher. Since the solution would likely be produced in lower volumes compared to standard air cleaners, tooling and production costs may become a significant challenge. Injection molds alone can cost tens of thousands of euros, and at lower volumes these large upfront investments are spread across far fewer units, driving the per-unit cost up dramatically and resulting in a considerably more expensive product for the customer.

Despite the higher initial cost, the developed solution may provide economic benefits over the lifetime of the vehicle. The increased dust holding capacity extends the service intervals between filter replacements, reducing maintenance frequency and unplanned downtime. This is particularly important in mining operations, where vehicle availability directly affects productivity and profitability. Reducing the number of filter replacements may therefore contribute to lower operational costs over time.

A lower pressure drop may also offer economic benefits by potentially reducing fuel consumption. This is because the engine has to do less work to draw in air when intake resistance is lower. However, this effect has not been validated through direct measurements; it is instead based on engineering assessments of the developed geometry and expected airflow behavior.

An additional advantage of the developed concept is that it maintains the original installation position within the vehicle. This reduces integration complexity and limits the need for modifications to surrounding vehicle structures. Alternative concepts proposed during earlier projects, as well as several competitor solutions currently available on the market, utilize installations behind the cab, which would likely require more extensive vehicle modifications and therefore higher integration costs.

Overall, the developed air cleaner will likely result in a higher initial investment but may provide lower total operational costs over the lifetime of the vehicle, particularly in demanding environments where minimizing downtime is critical.

5.6. Limitations and Future Work

A key limitation of the present work is the lack of physical validation of the developed concept. While the dust holding capacity was verified through theoretical scaling and filter media assumptions, the design has not been properly confirmed through prototype testing. Future work should therefore include full-scale physical testing in an airflow test rig to validate both pressure drop and dust loading performance.

In addition, the structural performance of the housing under real operating conditions has not been fully verified. Although the concept has been designed with consideration for pressure drop and packaging constraints, further analysis is required to evaluate its behaviour under vibration loads and dynamic operating conditions. This is necessary to ensure durability and to mitigate risks of deformation or structural failure.

The CAD models should also be further developed into designs ready for production. A more detailed structural optimisation is required, particularly regarding rib placement and reinforcement strategies, to ensure sufficient stiffness of the housing under pressure-induced loads.

Furthermore, CFD analysis of the internal flow distribution would be beneficial. This would enable a more detailed evaluation of pressure losses and airflow uniformity across the filter surface, as well as support further optimisation of the inlet geometry. While qualitative assessments suggest improved pressure drop characteristics compared to the reference design, quantitative validation was not possible within the timeframe of this project.

Finally, a pre-cleaner solution should be investigated as a complement to the main air cleaner in order to extend filter lifetime. This type of solution is already used by several competitors such as Scania and Mercedes Benz Daimler, and alternative concepts have also been explored internally within Volvo. However, the pre-cleaner was outside the scope of this thesis work and was not studied further.

7. Sustainability Aspects

Sustainability is a central part of product development within Volvo. The company has a strong focus on reducing environmental impact through innovation and efficient engineering solutions. These aims have also been important throughout this thesis work, where the focus has not only been to improve technical performance, but also to contribute to more resource-efficient and sustainable solutions.

The development of the air cleaner with an increased dust holding capacity contributes positively to sustainability from several perspectives. The increased DHC results in that the service interval for filter exchange can be extended since the filter is able to hold up to 4000 g of extra dust compared to the old filter. This results in fewer filter replacements over the vehicle's lifetime which reduces material consumption and waste as fewer filters need to be manufactured, transported and disposed of. Although the new design is larger, it lasts longer and reduces the need for replacements, which balances the extra material used.

Another important sustainability benefit is the optimized design for an even distribution of dust throughout the filter media. With an optimised inlet that is tangential to the filter, the internal air flow is steady which leads to that the dust loading across the filtering surface is evenly spread. This means that the available material is used more efficiently before reaching its functional limit. This prevents premature replacement caused by localized clogging and ensures that the full dust holding capacity of the filter is reached. This optimization maximizes the performance without over-dimensioning.

Furthermore, the design is optimized for a stable airflow with minimal pressure drop which indirectly contributes to an improved engine efficiency. The design reduces the risk of excessive pressure drop and ensures sufficient air supply to the combustion process, which supports optimal engine operation. Looking at commercial transport applications on a larger scale, even small efficiency improvements can lead to meaningful reductions in fuel consumption and emissions over time.

The new concept of the air cleaner supports Volvo's broader sustainability ambitions by improving component lifespan of the filters, reducing waste and promoting efficient resource use.

8. Ethical Aspects

The ethical aspects of this project are related to the transport industry's transition toward electrical vehicles. Since the developed air cleaner is designed for diesel-powered trucks, it can be questioned whether further investment in combustion engine technology is ethically justified today, since electrification is increasingly prioritized in the automotive industry.

However, even though electric vehicle technology is advancing rapidly, diesel-powered trucks continue to be important in global transport systems. They are expected to remain in operation for many years and diesel powered trucks are particularly important in applications where current electric alternatives face limitations related to infrastructure, range or payload capacity. From this perspective, improving the performance and efficiency of existing diesel trucks is ethically defensible, since it contributes to reducing environmental impact for diesel powered trucks during the transition period towards electric vehicles.

Optimizing the air cleaner performance means more efficient engine operation, a reduction of maintenance activities and extends component service life. These improvements reduce resource consumption and operational waste while enhancing reliability for applications where these transports are essential.

Volvo's investment in both electric and conventional vehicles shows a practical approach to sustainability. Improving diesel engine subsystems supports this by making current technology work as efficiently as possible while cleaner alternatives continue to develop. From this perspective, this thesis work can be viewed as ethically justified, as it contributes to optimization and development of current technologies while addressing current needs and working toward future sustainability goals.

9. Conclusions

This bachelors' thesis addressed the challenge of increasing the dust holding capacity of Volvo Trucks' air cleaners, while maintaining acceptable pressure drop, packaging constraints, and serviceability. The aim was to develop a conceptual solution that increases the capacity from 3000 g to 7000 g while preventing negatively affecting integration within the vehicle or introducing unnecessary complexity.

The project followed a structured product development process, including literature studies, competitor benchmarking, requirement specification, idea generation, and systematic concept evaluation. Both qualitative and quantitative methods were used throughout the project to support decision-making and concept selection.

The final outcome is a conceptual air cleaner design intended for heavy-duty diesel trucks, developed to achieve the targeted increase in dust holding capacity while remaining within existing packaging limitations. The concept was designed with consideration for airflow performance, manufacturability, and serviceability. The new air cleaner incorporated with the air intake system can be seen in Figure 30.

The results indicate that it is possible to significantly increase dust holding capacity within the given constraints, up to 7000 g. While the solution meets the defined targets at a conceptual level, further development and validation would be required before implementation in a production environment.

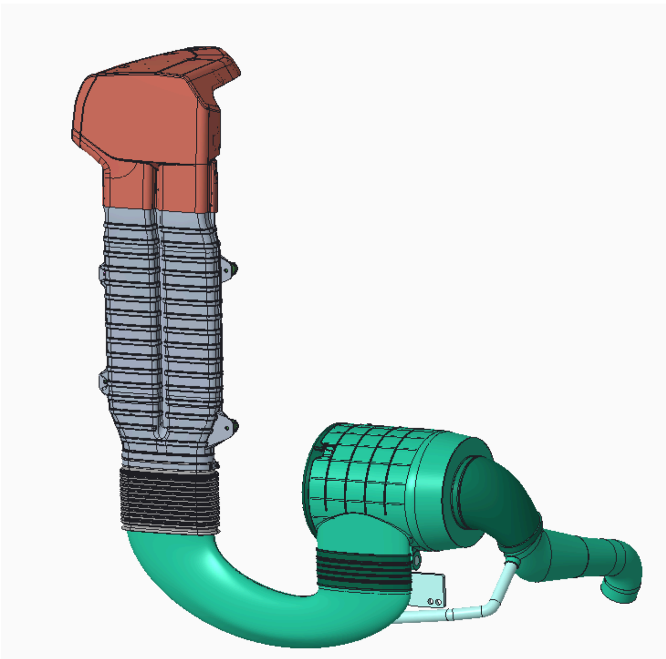

Figure 30: *Picture of the whole air intake system. Source: Own picture.*

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11. Appendices

Appendix 1. *Interview Notes – Meeting with Volvo Brand Representatives.*

Provided as a separate pdf file.

Appendix 2. *Interview Notes – Air Intake Specialist at Volvo Trucks.*

Provided as a separate pdf file.

Appendix 3. *Interview Notes – Discussion with Volvo Supplier Regarding Filter Media.*

Provided as a separate pdf file.

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