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An optimized packaging solution for cooling systems in cars

Master's thesis in Product Development

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Abstract

Competitors becomes stronger and stronger, new emissions laws and changing in customer needs, force companies to optimize their products and tools in order to remain or increase its market share. Volvo Cars will have the ability to build several models on the same production line. The architecture also provides advantages such as lower weight and better design proportions. The drawback of this is thus that volume inside the engine compartment has been reduced significantly. The future technology can be suppressed when the space inside the engine is limited for future components. Since more and more components that requires cooling have been introduced into the engine compartment, a major challenge has occurred from packaging point of view.

This master thesis has the aim to generate a concept that solves the packaging issue, a technical solution that optimizes the cooling system in order to optimize the packaging properties and free up space. In order to perform this thesis in a satisfied way, the concept development phases that is described by Ulrich & Eppinger (2012) have been utilized to follow each stage in a correct way. From the identification of customer needs, establishing initial requirement list to generate concepts and perform concept selection. The end of the development process consisted of an iterative process approach where ideas and concepts were developed and refined in order to make the result more realistic and applicable.

The final result from the development process is a concept which have been developed by combination of two concepts. Currently the transportation of coolant occurs by means of hoses, instead, this concept enable a transportation of coolant between components through internal channels in a block. In addition, the components are attached directly to the block, making it a single unit. A plastic construction enables the channels inside the block to adopt more narrow radiuses, something that is a major limitation with the use of hoses.

The area where the concept must be adapted to, is predetermined, which means that the concept has been adapted to its environment. The benefit of adapting the concept to its environment is that primary frees up valuable space in engine compartment but also saves weight. Since the packaging properties have been optimized by using this concept, the freed up space can thus be utilized to introduce new components, which strengthens the company's position in the market.

The concept is presented as an applied concept and as modular concept to show how the concept with some modification can be applied in different areas. A 3D-model was established for the applied concept and placed in an assembly for an existing car. The model was used to visually describe the concept where its benefits are highlighted.

In the end of this process, other applicable areas for the block that have been considered as relevant have been pointed out by the authors as a further examination for Volvo Car Corporation.

Preface

This paper is the result of our thesis conducted at the division Powertrain Geometry Assurance and Review at Volvo Cars in Gothenburg in spring, 2016. We want to thank all the people who have helped us during this time. Without your help and support, this work had not been possible to perform in a good way.

We also want to send a greeting to our colleagues in the department: Sören, Cattis, Philip, Filip, Kristoffer, Thomas, Marina, Anette, Eva and Torbjörn.

A big thanks to Torbjörn for the supervision during this time. Last but not least, we would also like to thank our supervisor at Chalmers University of Technology, Lars Lindkvist.

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1. INTRODUCTION

This chapter handles an introduction of Volvo Car Corporation and the aim of the project. Research questions, goal and limitations have also been stated here.

1.1. Volvo Car Corporation

Volvo group started to create vehicles in Gothenburg year 1927 and are today a global brand with manufacturing in Sweden, China and Belgium. They were owned by AB Volvo until 1999, where they was bought by Ford Motor Company. At 2010 Ford suffered economic losses and sold Volvo Cars to a Chinese company, Zhejiang Geely Holding which is still the owner today.

According to Volvo Car Corporation (2016) produces a range of different premium cars, sedans, sports wagons, wagons, SUVs and cross country cars. The company have around 26 000 employees with 61 % located in Sweden with their headquarters in Torslanda, Gothenburg.

Volvo Cars have a yearly sale of approximately 500 000 cars, distributed around the globe. Top 5 sales markets are: China (16.5%), Sweden (14%), USA (12.6%), UK (9.1%) and Germany (7.3%).

Vision and mission by Volvo Car Corporation (2016):

> "*Our vision is to be the world's most progressive and desired premium car brand. And we believe our global success will be driven by making life less complicated for people, while strengthening our commitment to safety, quality and the environment*."

1.2. Background

Nowadays companies around the world have to optimize their products or tools to stay competitive on the market. Demands on cost reductions, law regulations on emission and mass reduction are some factors that force companies to optimize**.** With this in mind, an increasing level of technology and higher customer demands on today's automotive industry leads to more complex powertrains for the vehicles. One reason for this complexity is increased number of components, which in turn limits the given design space for each system.

The geometry of the cooling system have reached its limits for the given design space, meaning that a new solution is sought with increased packaging properties. Improved geometry of the cooling system frees up space for future complexity in the powertrain. Another system that increases complexity in the cooling system is the electric hybridization, through increased number of cooling components.

1.3. Purpose and goal

The aim of this thesis work is to improve and optimize the geometry of the cooling system in automotive powertrain, with maintained serviceability, functionality, and production preparation. This improvement of geometry is critical in order to free up space for future complexity. This will be achieved by following the steps in the product development process, to reach a final outcome of one or several feasible concepts.

The questions below will be answered throughout the project in order to work towards the purpose of the project.

- Is it possible to improve the geometry of the powertrain cooling system with maintained serviceability, functionality and product preparation?
- Is it possible to improve the geometry of the powertrain cooling system with reduced cost, improved quality and/or increased ease of manufacture?
- Is the final concept innovative and involves new way of thinking?

1.4. Literature summary

To carry out the work effectively, the literature in the form of books, internet, articles and videos were utilized. The main literature regarding product development process, was achieved by using the book Product Design and Development, Ulrich & Eppinger (2012). Interviews and meetings were also executed in order to gain more in-depth knowledge.

1.5. Time plan

The work involves a degree at Masters Level. This includes 30 credits which is equivalent to 20 weeks of work. To make it clearer of planning and visualize the sub-objects in the work, a method called Gantt chart was used as a basis for the project, Appendix 1.

A weekly plan was set each Monday to distribute the work between the authors and to set a clear goal for each week, according to the Gantt chart.

1.6. Limitations

This thesis deals with engine cooling systems. But a solution for the entire cooling system would require considerably longer time than this project is set for. This mean that the project will mainly put focus on how to free up space in the engine compartment. However, the understanding of the entire cooling system and the car's components are essential and will still be processed, since it is important for the overall picture.

Since this project will handle the cooling system, some limitations are taken into account due to the complexity of the project. The main focus of this project will treat the packing space for the powertrain cooling system, with regard to the established requirements. The current cooling system occupies a lot of space, different needs and requirements on the system with varied importance which will be taken into account. These requirements have been divided into two categories, further called primary and secondary requirements.

Primary requirements:

- Optimize packaging space (improvement of geometry)
- Serviceability
- Functionality
- Production preparation

Secondary requirements:

- Cost reduction
- Improvement of quality

- Manufacturing (easy to manufacture)

This development process will be limited to mainly look at primary requirements stated above, which the product needs to fulfil. Secondary requirements will be a weighting factor between different solutions. Other factors like environment, efficiency, etc. will not be included in this project because of time limitations.

The final outcome of this project will be one or several feasible concepts, which means no prototype will be constructed. This is also due to time limitations.

2. THEORETICAL FRAMEWORK

This chapter deals with technical theory needed to get an understanding of the topic, which is necessary to complete the project in a satisfied way.

2.1. Cooling system

The purpose of the Engine Cooling System is to prevent the overheating of the vehicle's engine. With engine combustion reaching extremely high temperatures, the resulting heat needs to be dissipated. The engine cooling system consist of several different components that together keep the engine on an optimal working temperature.

According to Nice (2000) there are two different types of cooling systems, liquid cooling system and air cooling system. Today's cooling system consist mainly of the liquid based type, because of an increased efficiency and heat transfer capacity.

The air cooling system was used in older cars and are rarely seen in cars today. The engine has fins sticking out from the cylinders that transfer heat and picks up the airflow which cools the engine. The fan used for this type has greater power, in comparison to the liquid cooling system.

The most essential components that includes in the cooling system will be further described here below.

2.1.1. Coolant flow

How the coolant flows in the system and which components it consists of are explained by TheAutopartsShop.com (2013). The coolant can be set in circulation by the difference in temperature, but a more common way is to use a water pump for circulating the coolant in the system. The water pump can be driven by an electric engine or by a belt connected to the crankshaft. The coolant is then driven into the cylinder block and further up to the cylinder head to absorb the heat generated from the engine. The outlet from the engine is controlled by a thermostat, if the coolant is below the optimum service temperature of the engine it will go through the bypass hose and back to the water pump in order to accelerate the heating of a cold engine. When the engine have reached its optimal service temperature the thermostat opens the flow to the radiator. The radiator is often placed in the front of the vehicle, right behind the grill, where it is used as a heat exchanger which transfer the heat from the coolant to the ambient air that passes through the radiator. The fan is used to assist the airflow, especially when the vehicle is standing still. The cold coolant is then moving back into the pump and the cycle repeats.

When the coolant increases in temperature it expands and the system obtains a higher pressure, a pressure cap is used to avoid an increasing pressure of the system. The pressure cap is placed on the radiator and is spring loaded, when the pressure overrates the limit, the pressure cap opens a flow to the reserve tank (overflow tank). When temperature goes down in the system again the coolant from the reserve tank will be drawn back to the flow. The hot coolant from the engine is also used to heat the cabin of the car, this is done at the heater core where the hot coolant is used to heat air. A schematic over the conventional cooling system is illustrated in Figure 1 below.

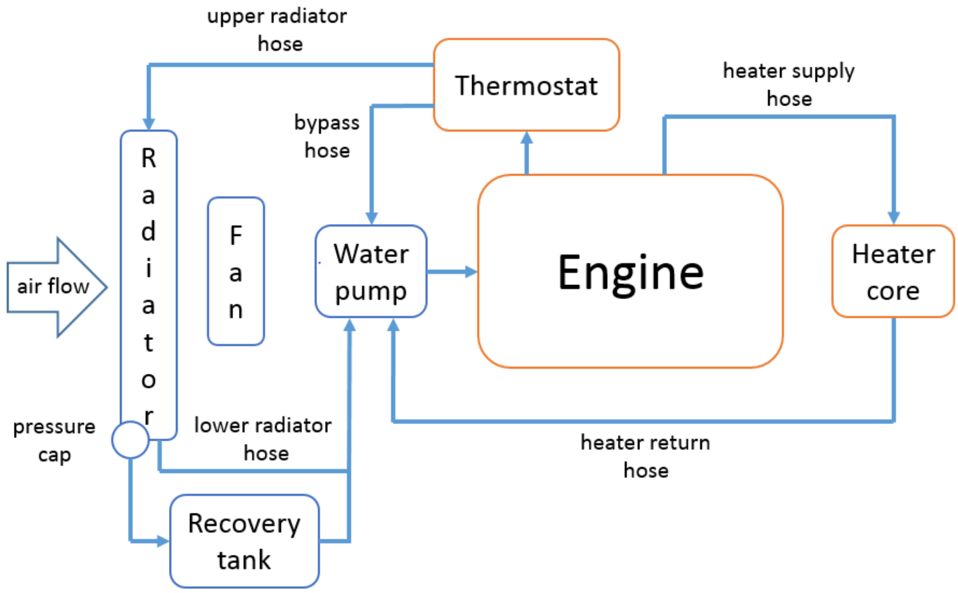


Figure 1. Conventional cooling system

2.1.2. Internal Combustion Engine

From 100 % fuel power at the combustion, about 25% is useful power. 70% of the power is heat where 40% is transported through exhaust gas and 30% is transported through the coolant. The last 5% is lost due to frictions. With this data given from the lecture Longo (2015), it is clear that from the fuel power, only a fraction is useable.

The engine is filled with passageways that allows the coolant flow inside the engine, these are either casted or machined in the engine block and cylinder head. These pathways enables cooling in the engines most critical parts which are around the cylinders, exhaust manifold and the exhaust valves.

Why should the engine operate at a certain temperature?

- Higher temperature of the oil for lubrication leads to lower viscosity which means less friction
- Lesser wear on metal parts
- High enough temperature to completely vaporize the fuel, leads to less emissions and a better combustion.

2.1.3. Coolant

In order to make the cooling liquid to sustain high and especially low temperatures, water is mixed with an antifreeze substance. This antifreeze substance is often ethylene glycol which is a 50/50 mix with water, depending on the climate the vehicle is driven in. The mix of water and antifreeze is called coolant. The mixture is not enough for raising the boiling point of the coolant, the cooling system is therefore put in pressure which is commonly around 1 bar. By using this pressure, it secures that the boiling point for the coolant will not be reached when engine is operating at high temperature.

2.1.4. Water pump

The water pump circulates coolant through the system to avoid locally overheating and proper cooling. The pump use centrifugal forces to accelerate the coolant, it is driven by a belt connected to the crankshaft. The coolant enter the centre of the pump and is driven by the blades to the outer house of the pump, where the outlet is located. The belt driven water pump can be replaced in modern cars by an electric water pump, to gain increased control over the unit. It is important that the water pump have a low position on the engine, to avoid air in the pump. If air fills the pump it inhibits the circulation of coolant.

2.1.5. Thermostat

The thermostat have two missions, one is to allow the engine to quickly heat up. The other one is to keep the engine at a constant temperature by regulating the coolant flow rate through the regulator.

In order to heat up the engine quickly, the thermostat is closed, which makes the hot coolant flow through the bypass and back to the water pump. Once the coolant reaches a certain pre-set temperature the thermostat opens, allowing flow from engine to the radiator. The thermostat has a spring loaded cylinder which is filled with wax and a rod. When the temperature is high enough the wax starts to melt and expand, pushing the rod out of the cylinder which opens the valve, therefor the coolant can flow through. In a modern vehicle the thermostat can be replaced with an electric water valve, which performs the same task but with more control and efficiency.

2.1.6. Radiator

The radiator is a heat exchanger which transfers the heat from the hot coolant to the air that flows through it, air from either the moving vehicle and/or from the fan. The inlet of the radiator is often at the top and the outlet in the bottom. Between the parallel tubes where the coolant is vertically flowing is fins that increase the turbulence of the air, which makes the heat transfer more efficient. Sometimes similar fins are also placed inside the tubes to increase the turbulence of the coolant as well. The radiator is usually constructed in aluminium with plastic tanks on each side.

2.1.7. Pressure cap and reserve tank

An expansion will occur when the temperature increases in the coolant which causes increased pressure. If the pressure exceeds 1 bar, the pressure cap opens by a spring and allows coolant flow to the reserve tank. Works the same way if the pressure falls down below 1 bar, it creates a vacuum which pulls coolant from the reserve tank by another spring loaded cap back into the system. Thereby the system can keep a constant pressure determined by these spring caps without slipping air into the system.

2.1.8. Heater core

The heating system is similar to the cooling system, where the heater core is a small radiator. Hot coolant flows from the cylinder head, through the heater core and finally back to the water pump. A fan blows air through the heater core, where the heat from the coolant is transferred into the cold air, the air is then further blown into the passenger cab. This process will run regardless of the thermostat and explains why it takes time before hot air reaches the passenger cab from a recently started car. As the heating system relies on hot coolant the engine needs to raise in temperature before the heat exchange is possible.

2.1.9. Hose

Hoses connects the cooling system and directs the flow of coolant between components. According to AASA (2016) the most commonly hoses are made out of EPDM rubber which can endure both high and low temperatures, silicon hoses also occurs which can withstand an even higher range of temperature. Almost all hoses in the powertrain are curved or moulded to fit the specific application of the vehicle, this is needed due to packaging reasons, to utilize the space. Many car manufacturers uses spring-type clamps to attach the hoses to different connections, which puts a constant and even pressure over the hose, but quick connectors also occurs where space is limited.

The most recurring reasons for hose failure are electrochemical degradation, which occurs when coolant, hoses and various types of metals in the powertrain combine and creates an electric current flow through the system. This current creates cracks inside the hoses and with the pressurised system the coolant is penetrated through the fabrics of the hoses. Another reason for failure is when a hose have been continuously exposed to hot oil from leakage in any oil cooled component.

3. METHOD THEORY

This chapter describes the theory regarding the different methods that have been utilized in order to execute this project.

3.1. Product development process

In order to create a successful product, a product development process consisting of a number different steps and methods are essential. A product development process is a process consisting of steps activities that can be used by the development team in order to conceive, design and commercialize a product. The basic principle of the product development described by Ulrich & Eppinger (2012), which is built on six steps or phases, see Figure 2. Basically the process starts with planning and ending up with production where the product is created. Between these two phases the development team will pass through four more phases that requires a lot of resources and time since every new product needs to pass through this series of stages from ideation through design, manufacturing and market introduction.

Figure 2. Product development process by Ulrich & Eppinger (2012)

There are several benefits of using a well-defined development process. One essential benefit is the quality assurance of using this process. Since the process requires to specify the phases that the team will pass through, the quality for each phase will be checked before entering the next stage. Thus, this assure that the overall quality for the entire process will be at a satisfied level. Another benefit is the planning time. Due to that the development process includes milestones for each phase, meaning that specifying the time for each milestone will anchor the overall time for the project.

3.2. Planning

The first stage in the product development process is the planning phase where this phase begin with identification of opportunity. With other words, at this stage identifies the assessment of technology developments and market objectives.

The result at the end of this stage is that the product mission statement is specified. This means that the target market for the product is specified which includes the business goal and constraints.

3.3. Concept development

The next level after the planning stage is the concept development stage. Most of time and resource will be utilized at this stage since the outcome of this will be identification of the needs of the targeted markets. Several product concepts are also generated, screened, evaluated and selected for further development and investigations.

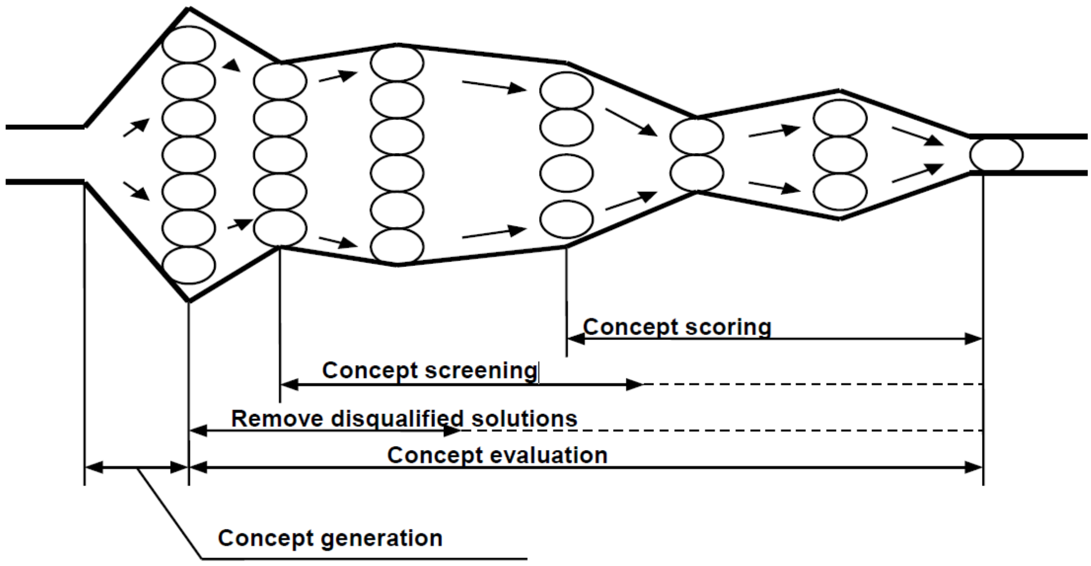


Figure 3. Concept development, narrowing the tunnel. Image from Almefelt (2015) systematic design lecture

The concept development consist of several different steps, see Figure 3, where it starts with identification of customer needs and ends up with modeling and prototyping. The process aims at initially generate as many concepts as possible and then start to narrow them down until one concept remains. As knowledge is built up during the process new concepts will appear, can also happen by combining different solutions.

3.3.1. Identification of customer needs

The aim of this stage is to understand the need and wants from the customer where the market research help the development team to understand what the customer needs. The first step in this process is to gather raw data from customers, which can be done by e.g. interviews, focus groups and observations. After the raw data is gathered it needs to be transformed into customer needs. The result from this stage is a set of customer needs that are listed and weighted according to the importance.

3.3.2. Establishing the requirement list

By understanding the customer needs and wants a requirement list can be established. A requirement list provide a description what the product needs to fulfill. With other words, the needs from the customer has been translated to technical term. In the beginning of the concept development the requirement list is not precise, rather more wide and open to avoid limits for the creative process. Later in process the list becomes more refined and precise, called a target specifications.

3.3.3. Concept generation

One of the most critical stages in the engineering design process is the concept generation. The aim of this stage for the product development team is to come up with new ideas. A concept can be described as an abstraction or realization of an existing idea. More specific, a concept can be expressed as a three-dimensional model. Basically a concept generation is a process of composing a desirable concept for the future. Before beginning this stage the team need to state the needs from the customer and also target specification, further called requirements. An important aspect to take into account is generate as many concepts as possible since a failure of some concepts are inevitable. Even the most creative and crazy ideas should be created which may lead to something useful for the project and provide with new knowledge. The end of this stage will result in a set of concept alternatives that will be picked for the next stage which is the concept evaluation consisting of elimination, concept screening and concept scoring.

3.3.3.1. Brainstorming

To generate as many concepts as possible, different methods can come to great use. One of the most common is brainstorming, which is described by Mind Tools Editorial Team (2016). This technique is both a group and individual creativity technique which efforts are made to find a conclusion for a specific problem by gathering a list of ideas contributed by its members. Brainstorming can be divided up into two aspects, individual brainstorming and group brainstorming where the latter one is often more effective at generating ideas. Individual brainstorming is most effective when you need to solve a simple problem, generate a list of ideas or focus on a broad issue. Group brainstorming is often more effective for solving complex problems where it is necessary to take advantage of the experience from the group members.

6-3-5 method:

The webpage InnovationTools.com. (2013) describes the brainstorming technique called 6-3-5. This method is consisting of 6 participants who required to write down 3 ideas within 5 minutes. This procedure will be performed six times since the worksheet is supposed to pass it forward to the next participant before it returns back after six rounds. This procedure will generate 108 concepts in roughly 30 minutes which is a great tool to use in order to generate as many concepts as possible. This procedure can also be used for less or more than six participants. A drawback with having too many participants for this technique is that adding only one more participant will possible add 39 more concepts to deal with.

Lotus blossom technique:

Lotus blossom technique is an idea generation technique that according to Riley (2013) can generate a lot of creative concepts. This technique is based on having the main topic in the middle of the 3x3 matrix. The next step is to generate eight concepts (one concept for each box) that are related or solutions to the main topic. After this step, for each concept that have been generated, same procedure will be performed as for the main topic. This means that up to (8x8) 64 different concepts can be generated from this technique, see Figure 4.

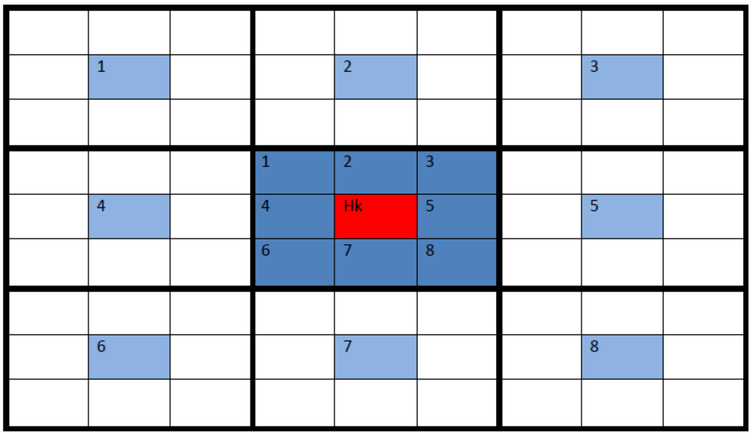


Figure 4. The Lotus technique

Contrariwise method:

Another method that can be used for brainstorming is the "contrariwise method". Westling (2011) describes this as an idea generation method that formulates the problem of the opposite of the thing you want to accomplish. How can this product be made as useless as possible? People often has more ease to find the negative aspect of a product where this method applies it for creative thinking. When negative aspects have been found, it is time to translate the opposite positive definition. How can this negative aspect be avoided and what's the positive opposite? When the positive opposite is found, the group have to think about how to achieve it in creative ways. By using this method some aspects that were taken for granted and not thought of can appear and may give a new perspective of the problem.

Mind maps:

Mind maps are a very effective method to help the brain to take in new information and remove unnecessary information. In Mindmapping.com. (2013) the method is explained as a creative and logical method for creating new ideas and ensures that all ideas are collected in one place. This method may also result in the ability to put ideas into groups, in order to get a better overview. One of the benefits of this this method is the visualization of the correlation between different points.

3.3.3.2. Benchmarking

Benchmarking is useful in order to increase knowledge about the system and to gain inspiration on different solutions, to identify how the competitors have done to solve the same problem. By means of this method, Westling (2012), one can identify what makes a product successful from a customer viewpoint.

Benchmarking can be computed in many different ways, for example by directly investigate the competitors product. Another way is to reach the customers and ask them why they buy/prefer a specific brand rather than other products which delivers the same main function. It is important to look at competitors within the same price range, but also to explore how a more premium or basic product have solved the problem and identify what parameters that influence the cost of the product.

3.3.3.3. Morphological matrix

In the lecture systematic design, Almefelt (2015) explain the morphological matrix as a useful tool for generating ideas and concepts in an analytical and systematic manner. This matrix begins with having sub-function at the left column and different solutions for each sub-function at the right columns, where these solutions will form the components in the morphological matrix see Table 1.

Table 1. Example of a morphological matrix

Sub-functions	**Solution alternatives**			
1	A1	B1	C1	D1
2	A2	B2		
3	A3	B3	C3	
4	A4			
5	A5	B5		

For this example the numbers in the left column is the sub-function and the right columns, consisting of letters and numbers, is the solutions for the sub-function in the same row. Basically different solutions are found by choosing one alternative from each sub-function. With other words, each combination of alternatives creates a solution to the problem. Choosing a combination of different alternatives does not lead spontaneously to a solution to the overall problem. The combination of fragments must usually be developed and refined before an integrated solution emerges. This matrix above (Table 1) can thereby give 4x2x3x1x2 = 48 different concepts or solutions. An important thing to have in mind is that all possible combinations or solutions from the matrix is not always realistic since some of the solutions will contradict to each other. This means that those concepts that are realistic is often less than the number of possible concepts that can be generated from the matrix.

3.3.4. Concept evaluation

First of all it is necessary to identify the customer needs that requires to be fulfilled as stated above. The next step according to Ulrich & Eppinger (2012) is the generation of different concepts that fulfils the needs, which can be performed by using different methods as described in previous section. Concept evaluation is the next step in the process where this stage aims to evaluate the concepts with respect to customer needs and other criteria and also comparing the relative strengths and weaknesses of the concepts. With other words, this stage is the process where it is necessary to narrow the set of concepts. At the end of this stage by means of different methods, the team will select one or more concepts for further investigation, testing, or development.

The concept evaluation stage is consisting of three stages to manage the complexity of evaluating the high number of product concepts. The first stage is elimination, the second is concept screening and the last stage is concept scoring. These three stages can be performed by using decision matrices specified for each stage. The concept matrices is organized by the requirements, and includes numerical values for target specifications as well as observed specifications for a list of potential solutions. The elimination stage is used to remove all obvious disqualified concepts, screening stage is used as a process to reduce the concepts to few viable alternatives. The scoring stage on the other hand, is more precise analysis of the remaining concepts in order to choose the single concept that will be improved, refined and later on developed.

To be able to perform the concept selection well, a six-step process is used as a reference. These six steps is used in both concept screening and scoring. These steps are:

1. Prepare the matrix selection.
2. Rate the concepts.
3. Rank the concepts.
4. Combine and improve the concepts.
5. Select one or more concepts.
6. Reflect on the results and the process.

3.3.4.1. Elimination matrix

The result from concept generation is a high number of different concepts, to be able to reduce this number of concepts and at the same time verify that these concepts fulfils the customer needs, an elimination matrix is often used. This matrix is used to eliminate obviously disqualified concepts before the more time consuming matrixes are used. Examples of criteria from Almefelt (2015) that can be evaluated are:

- Does the concept solve the main problem?
- Does it fulfill requirements and demands?
- Is it safe?
- Is it realizable?

The concept should be eliminated if it fails on one of the stated criteria, therefore the criteria should not be complex to avoid a strong filter. The elimination matrix saves time for the upcoming methods by removing concepts that would be eliminated in a future stage.

3.3.5. Concept screening

To be able to screen the concept in a systematically way, a method called Pugh matrix is often used. Since the aim of the screening stage is to reduce the concepts, this method is a helpful tool to use in order to pick the concepts that will be evaluated in scoring stage.

3.3.5.1. Pugh matrix

At this stage, a number of different concepts have been developed in the previous stage (concept generation) in order to perform this matrix. At the beginning of this matrix, a number of different criteria have to be selected within team since the concepts will be weighed against these criteria. These criteria are chosen based on the customer needs which the team has identified. After the identification of the criteria, the next step is the decision of a reference concept that all other concepts are rated against. The reference concept can be a similar product from the competitor or a standard product.

Step 2 and 3 is to rate the concepts against the criteria and after the rating, ranking the concepts. The best and easiest way to rate the concepts is using "+" as better in comparison to the reference, "0" means equal or "-" worse than the reference. The reference concept will always have "0" in every criteria. This procedure will be performed for each concept. After rating all the concepts, a summary of "+", "0" and "-" will be done for each concept and enter the sum for each category in lower rows of the matrix. The concept with highest net score will be ranked as number one and next one as number two etc. A net score can be calculated by subtracting the number of "-" ratings from the "+" ratings see Table 2.

Table 2. Example of a Pugh matrix

	Concepts					
Criterias	**A (ref)**	**B**	**C**	**D**	**E**	**F**
Volume reduction	0	+	0	0	+	-
Cost	0	0	0	-	0	+
Ease of manufacture	0	+	+	-	-	0
Perceived quality	0	-	+	+	-	-
Performance	0	0	0	+	+	+
Servicability	0	+	+	-	+	0
Sum +	0	3	3	2	3	2
Sum 0	6	2	3	1	1	2
Sum -	0	1	0	3	2	2
Net score	0	2	3	-1	1	0
Rank	4	2	1	6	3	4
Continue?	No	Yes	Yes	No	Combine	No

Next step is to consider if the concepts can be improved or combined in order to achieve better concepts. If it is possible, the new improved concepts that have been created by combination of other concepts are added to the matrix and rated along with the previous/original concepts. The matrix will be performed again with the new concepts where the concepts will be ranked and rated as previously. The matrix can be performed again if many concepts get the same net score and it is hard to determine which concepts to take into further studies, a better result may be obtained by changing the reference concept. The remaining concepts from this matrix will thereafter be further evaluated in the next stage which is the scoring stage.

3.3.6. Concept scoring

After concept screening have been performed, only a few concepts should remain. Concept scoring is used to evaluate these remaining concepts with further precision and to ease the decision making on which concept to take further into development. One valid method for scoring concepts is the Kesselring matrix.

3.3.6.1. Kesselring matrix

In the Kesselring matrix the concepts are compared to each other with weighted criteria, depending on the customer needs and the importance of the criteria they are assigned with different weighting factors. Pair wise comparison is one method for weighting these criteria where two criteria is weighted against each other and are compared as equal, or one is of greater importance. This weighting can be used as a percentage of 100 allocated to the criteria, or on a scale.

When the weighting is set the concepts are rated from a reference concept, which often is an optimal solution. The rated value are multiplied with the weighted value to get the total value, all these total criteria values are added and generates the final value for the concept. From this value a ranking can be made, see Table 3. In the concept scoring a lot of knowledge can be gained, advantages and disadvantages of different concepts which then can be combined in the same way as in the concept screening.

Table 3. Example of a Kesselring matrix

		Concept A		Concept B		Concept C	
Criterias	**Weight**	**Value**	**Total**	**Value**	**Total**	**Value**	**Total**
Packaging	25	3	75	2	50	4	100
Servicability	15	2	30	4	60	3	45
Functionality	15	3	45	4	60	3	45
Production preparation	10	4	40	2	20	2	20
Cost	15	5	75	3	45	1	15
Perceived quality	10	1	10	3	30	2	20
Ease of manifacture	10	3	30	1	10	4	40
Total score		305		275		285	
Rank		1		3		2	

The result from the Kesselring matrix is one final concept to take into testing and further development. Important aspect is to check the variance in weighting and rating of the criteria and how it influence the result of the matrix. A concept may be preferred if it has low uncertainty regards the given rating and on the other hand a high ranked concept with uncertain rating may be less desirable than intended.

3.3.7. Concept testing

Concept testing is the process of using quantitative method and qualitative method to evaluate customer response to a product idea before introducing the product to the market. The idea with this stage is to prevent the failure of the product in early stage since changes in design is less costly in early stage rather late in the process. Another benefit of having the concept testing is to select which of the concepts should be pursued, to gather information and ideas from potential customers on how to improve a concept.

To be able to perform a concept testing, a seven-step method described by Ulrich & Eppinger (2012) are used as a reference. These steps are:

1. The definition of the purpose of the concept test.
   Writing the questions that needed to be answered by the customer.
2. The choice of a survey population.
   Choose a population that mirrors the target market in many ways.
3. The choice of a survey format.
   Choose the right survey format that suits for your purpose. E.g. Internet, face-to-face interaction.
4. Communicate the concept.
   This step is closely linked to the previous step, where the concept can be communicated in many ways. E.g. verbal description, sketch etc.
5. The measurement of the customer response.
   The measurement is done by letting the customers have a scale from 1-5 where 1 is "would not buy" and 5 is "would definitely buy".
6. Interpret the result.
   An interpretation of the results is useful when the team is interested in comparing two or more concepts.
7. Reflection on the result and the process.
   Reflect on the outcome of this process and the result. Is the result satisfying?

3.4. System level design

A system level design process is a key issue for a successful development of products. At this stage one concept has been chosen and the aim of this stage is define the product structure, layout and the components that will be a part of the entire product. In addition to this is that a functions description for each sub-function is also performed and the assembly process.

3.5. Detailed design

The detailed design process transforms concept alternatives, preliminary physical architectures, design specifications and technical requirements into final design definitions. This is one of the development stages that requires a lot of time since all necessary information for each sub-component need to be find. During this stage, all calculations for the product is performed, the material selection for each component etc. The outcome of this stage is to produce drawings of the component and generate the necessary basis for the product, in order to prepare the product for production. When these tasks are performed, the product is ready for prototyping.

3.6. Testing and refinement

During this phase, prototypes have been developed in order to demonstrate the functionality and help to solidify the requirements for the final design. At this stage testing and refinement will be conducted for the concept in order to finalize the final design. The prototypes will be evaluated, tested and further developed, to ensure that components and subsystems of the product work together as expected, and also that the requirements and needs from the customer are fulfilled.

There are two types of prototypes called α-prototypes and β-prototypes. The different between these two types are the manufacturing and assembly process. The α-prototypes have often right material selection but another type of manufacturing and assembly process, in order to minimize the cost of tools. When the function of the prototype are ensured and the product work as expected, the β-prototypes are developed, where these types of prototypes will have same manufacturing and assembly process as the real product.

3.7. Production/Ramp up

When the final design is set up and the testing are completed, the requirements and the market analysis are satisfied, the next and thus last stage in the product development process is the production for the product and also the ramp up of the product. Since the production processes will differ from product to product, it is essential to realize that right production process for the specific needs and quantities of each product is key to success. This, to prevent other cost such as high tool cost for example.

4. Implementation

The following chapter explains the workflow for this project. The thesis has followed a product development process that has been described by Ulrich and Eppinger (2012) - Product Design and Development. From idea and concept generation and concept selection to detailed design while constantly developing underway, for improving the results.

4.1. Pilot study

The first week of this period consisted of a collection of information on the topic concerned. The cooling system and its surrounding components where studied and benchmarking was conducted on two car brands (read section 4.3. Benchmarking) to get more information concerning different cooling systems. Literatures on different methodology were examined as well. In addition to this, the work was planned and divided to make it clear and well-defined objectives were set up.

The car's components were studied by a number of different activities such as interviews with knowledgeable people in Volvo Cars see Appendix 3 and Appendix 4. In addition to that, the software TeamcenterVis was frequently used to get more information and more understanding about the system. To get a deeper understanding of engine operation, the authors underwent a teaching of the engine components by the supervisor at Volvo Cars. This was very useful to get a great overview of how different component interact to each other and a better knowledge of each component. For example where the heat comes from and how it travels, gives understanding why components needs cooling.

To increase the understanding and knowledge regarding cooling system different articles were studied. In addition to the articles, different videos from Internet were utilized since it come to a great use as well.

4.2. Identification of customer needs

Ulrich & Eppinger (2012) mention that concept generation stage starts after the identification of customer needs. With this in mind, an initial requirement list was created and set up. This were already performed by the supervisor at Volvo Car Corporation before the project started. The requirement list was initial at the beginning of the project to keep it wide and open in order to not prevent the creative process, but later in the process the list become more refined and precise.

4.3. Benchmarking

A benchmarking have been performed for the engine cooling system where this activity has been performed in two ways. One way was based on using a specific internet website called a2mac1. This website had roughly all car brands around the world, where this website provide the user with information about every single component in each car model. The information gathered from this website were used in order to gain knowledge about how different car competitors have solved same problem, but in different ways. To be aware of different viewpoint is very useful for the idea generation since it can generate many different concepts.

In addition to this way of benchmarking, an observation of the engine in two different car brands was performed. The car brands in this case were Volkswagen and BMW. The similarity for this two car models were that the engine in both cases was a four-cylinder diesel engine.

The observation of the models is described below:

Volkswagen 2,0TDI

- Engine is positioned transverse.
- Limited space at the front grill.
- Hoses goes along with the body.
- It exist several branching points which decreases space.
- The hoses is made of a stiffer elastomer or a combination of elastomer and metal.
- Existing components: Auxiliary pump, pump heating system and regulator valve.

BMW GT 320d

- The engine is positioned longitudinal.
- The hoses is made of soft elastomer.
- Engine Oil Cooler (EOC) is in a higher position.
- Auxiliary components are not used in this system

As it shown, there are some differences between these models. One huge difference is the position of the engine, where Volkswagen has positioned in transverse way while BMW positioned in longitudinal way. Longitudinal engine means that the crankshaft is oriented along the long axis of the vehicle, front to back. Transverse engine means that the engine's crankshaft axis is parallel to the driveshaft of the vehicle. The choice between these two positions is primarily due to space saving and also time and cost saving, also determines if it is front or rear drive.

The hoses for these models were made of elastomers in both cases, with the difference that hoses in Volkswagen model perceived stiffer in comparison to the BMW model.

4.4. Brainstorming

To perform a successful brainstorming session, different methods have been utilized. The methods described below have been used both by the authors and within the department.

4.4.1. Mind maps

In the beginning of this session, a lot of ideas regarding the cooling system needed to be generated, mind maps was used as a method to generate the ideas.

There exist two types of maps for this case, one regarding the hoses in the cooling system and one regarding other components in the system that are related to the cooling system, e.g. the radiator, engine water pump etc. This division has been performed early in the process, when authors believed that the hoses in the system takes a lot of space and also the hose routings are in an unstructured way.

The result is illustrated in Figure 5 and Figure 5 where the first mind map has eight different ways of how to improve the hoses in the system and the latter mind maps consist of seven different ways and ideas on how to improve the components that are connected to cooling system. A notice is that these ideas are open and wide at this stage.

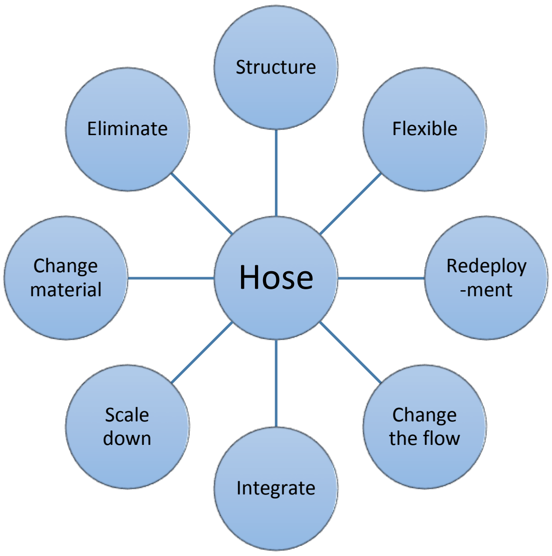


Figure 5. Mind maps for hoses

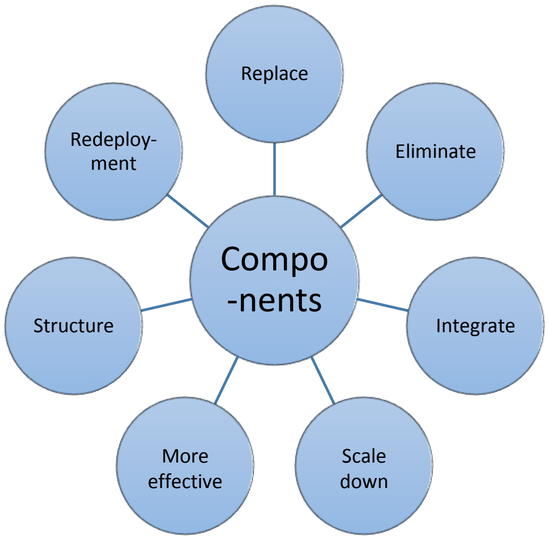


Figure 6. Mind maps for other components

4.4.2. Lotus blossom technique individual

In order to come up with ideas, the lotus blossom technique came to a great use. The authors started to have the main problem in the middle of the matrix which is "free up space". The result of this method is to generate eight different solution for the main problem. The next step was to generate eight sub-solutions for each solution. The result of this performance was 64 ideas of how to deal with the main problem, where some of the ideas were similarity to each other, see Appendix 5.

4.4.3. Contrariwise method

This method was used in order to think in a different way. How do we make the cooling system as useless as possible? With respect to the requirement list. By stating this question, several ideas of how to make the cooling system useless were stated. The next step for this method was to translate these negative ideas into positive. For example, make components as big as possible → compact components with maintained performance. For more example see Appendix 6

4.4.4. Lotus blossom technique group

To be able to perform this method in groups, gathered seven people from the Powertrain Geometry.

This method is divided into two parts. First part meant that each team member completed a Lotus paper individually during 10minutes where the main topic was to free up space. Eight sub-solutions each would generate 56 (8 * 7) different sub-solutions.

After the execution of this part, the next step was to pick 4-5 sub-solutions from this 56 sub-solutions for further investigations, meaning that eight sub-solutions would be generated for each of these picked solutions from the first part. The reason why a limited number of sub-solutions was picked was mainly due to the time-limitation which was only one hour for the entire group idea generation. The activity of picking sub-solutions to further investigation was based on new interesting areas that's not been discussed before or if a previously discussed area have a lot of potential to free up space where additional interesting ideas could be found.

The next and thus last part of this session was to generate eight solutions for each picked sub-solution in group. The effect of using the whole group in this session was to get many views and ideas from different people and to freely discuss about different solutions. Ideas from one person might trigger someone else's brain activity and inspire each other for more ideas.

This group session was performed to validate the current idea list, to see if some area or aspect were completely missed by means of previous idea generation methods. But also to include the different knowledge, experience and ideas amongst the group members, see Appendix 7.

4.4.5. 6-3-5 – method group

After the execution of part 1 and before the beginning of part 2 in the Lotus Blossom group session, there was a gap where it was essential to collect all 56 concepts generated by the group to pick four to five sub-solutions as described in the previous section. During the compilation of the concepts, the group performed the method 6-3-5, which meant six participants, three ideas each, in five minutes. This method was modified to 7-1-1 instead, this because of lack of time, where it was necessary to reduce the number of ideas to one each in a minute instead, see Appendix 8.

4.5. Elimination of ideas

4.5.1. By using expertise

After compilation of the developed ideas, the next step was to eliminate certain ideas that did not meet the requirements, were not realistic or did not fit the timeframe. In the beginning of this stage, the number of developed ideas was roughly 85 where some of them were more open ideas and other were more closed and specific.

To be able to reduce the number of ideas, people with long experience within the field were invited to a meeting. An interview were set up with Sundemo (2016) and Andersson (2016). The idea of having an interview with the expertise people is, by looking from their point of view, get a good and fast evaluation of which of the ideas are reliable and which are not. By involving expertise in this stage saves a lot of time for the project as each of the 85 ideas do not have to be studied and evaluated by the authors.

The result from this activity was a significantly reduced number of concepts, from 85 to 34 ideas.

4.5.2. Individual elimination

In this stage, a number of 34 ideas remained from the previous section, which means that it was necessary to iterate the elimination step once again in order to achieve smaller number of ideas. Before starting with this process, the remaining ideas were reduced to 25 where this result was achieved by combining some ideas and eliminating ideas that were similar to each other. The next process was done by the authors, which means that, by discussing and brainstorming, eliminate those ideas that does not fit the timeframe, has lower potential regarding packaging properties since one desire is to free up space as much as possible.

The result of this activity was a reduction of ideas, from 25 to seven ideas were achieved, see Appendix 9.

4.6. Idea rating

At the beginning of this stage, seven ideas were collected. The seven remaining ideas where gathered in a document where every idea had a short description, pros and cons list and some pictures to illustrate how the idea may look, to assist the understanding from the description, see Appendix 10. Every idea page also included a comment field and a rating box. This document was sent to seven people within the cooling and packaging groups. The people chosen to be involved in this evaluation was based on their knowledge about the cooling system and if they could deliver a valuable feedback and a fair rating of the ideas.

By comments and ratings the ideas could be further evaluated and eliminated. The optimal choice of idea comes with a high rating from both packaging and cooling. If they both rate an idea high means that it have great potential to reduce volume and also maintain key functions for the cooling system.

After the execution of the idea rating, it resulted in three remaining ideas with the highest potential. The rest of the ideas were thereby eliminated, see Appendix 11.

4.7. Description of idea group

From the previous section the remaining idea groups were the block, the fan shroud and hose profile. Short description of each idea group is described below:

The block:

The idea is based on creating a block with internal channels where different types of components, such as EWP, separator and thermostat can be connected directly on the block. In this way, more free space is obtained by eliminating multiple hoses.

The fan shroud:

Currently it exist long hoses around the fan package which take space. This idea is based on shortening the large radiator hoses by distributing water through the fan package. This will reduce the length of the hoses and the distance travelled on the engine side.

Hose profile:

Today's hose profile has the circular shape which is the standard hose profile at Volvo Cars. By having circular hose profile poorer stacking properties are obtained. Changing the hose profile to another type of shape, for example square, enable better stacking properties which in the end will result in more liberated space.

Through a discussion between the authors resulted that the latter idea group was eliminated. This was modified to two ideas since the authors decided that the third idea had the lowest potential regarding free up space and it could be combined with the other ideas. For a more detailed and describing description see Appendix 12.

4.8. Concept generation

Concepts were needed to be generated for the two ideas that remained from the previous section. The goal with this stage was to create concepts that fulfills the ideas. But since it exist time pressure for this project, the number of concepts for each idea was limited to two-three concepts. This means, a collection of four-six concepts were the aim to reach.

To be able to generate concept that fulfills the ideas, a brainstorming session was started to collect the sub-functions in order to generate sub-solutions. By breaking down solutions into sub-functions, a morphology matrix can be utilized in order to create different concepts. Some concepts will be eliminated since some will not be reliable, similar to each other or contradict each other.

4.8.1. Morphology matrices

In order to create the concepts, two morphology matrices were used, one for each idea. The idea of having two different matrices was done since the sub-functions were different for the both ideas. This led to that the sub-solutions become different as well.

4.8.1.1. Fan shroud

The fan shroud was one of the two ideas that was highly ranked by the packaging and cooling group. This matrix consist of three sub-functions where each sub-function have three different sub-solutions. The sub-functions are *water distribution*, *from shroud to tank* and *channels in shroud*, see Figure 7. This can, mathematically, generating (3^3) 27 different concepts. But in reality, this number is lower because some concepts will be similar or not realistic. It is also possible to evaluate the sub-solutions individually in order to find the optimal solution.

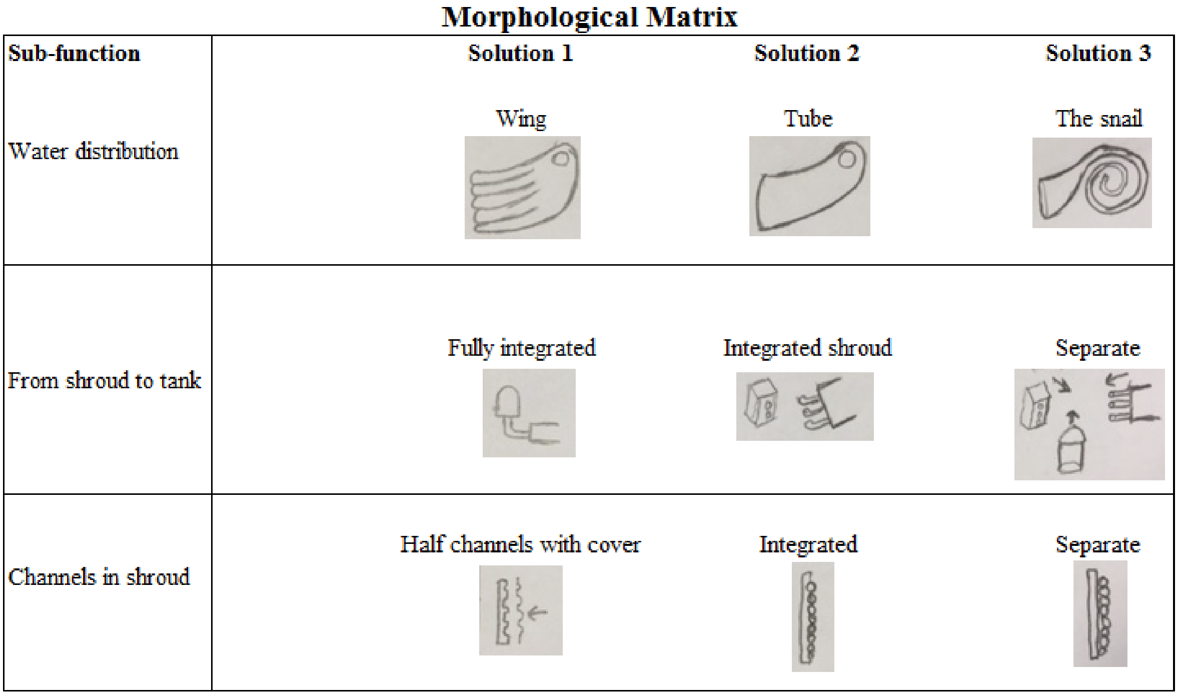


Figure 7. Fan-shroud - Morphology matrix

From 27 possible concepts that can be generated from this matrix to three concepts were achieved after the compilation of the matrix. The combination of sub-solutions for these three concepts is described below. A part to mention is that the material for these concepts is plastic since the fan shroud is made in plastic as well.

Concept 1 – The wing:

The water distribution for this concept will have a shape of a wing with internal channels .The attachment is separate from shroud to tank and half channels with cover.

Concept 2 – The tube:

This concept has a shape of a tube to fulfil the water distribution function. The tube is fully integrated to the tank where the channels also are integrated into the shroud.

Concept 3 – The snail:

The last concept from this idea group has an appearance of a snail as a shape to fulfil the water distribution. This shape is integrated to tank where the channels is separated from the shroud.

4.8.1.2. The block

The other high ranked idea is called the block since the entire solution will be based on a block. This matrix is quite larger in comparison to the matrix in the previous section. The morphology matrix consist of six sub-functions with a total number of 16 sub-solutions. The sub-functions for this matrix are *shape*, *thickness*, *channels*, *cut, attachment* and *material*. This can thereby, mathematically, generating (3x2x3x3x3x2) 324 different concepts see Figure 8. As mentioned in the previous stage, this high number of concepts will be lower in reality.

Since 324 different concepts is not possible to evaluate due to the time frame that the project must operate within, only one-two sub-solutions were selected for each sub-function. By executing in this way, the number of possible concepts could significantly be reduced.

Morphological Matrix

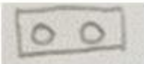
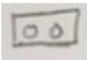
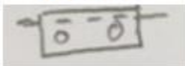
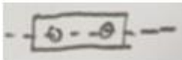
Sub-function	Solution 1	Solution 2	Solution 3
Shape	Block 	Fork 	U-Block 
Thickness	Simple 	Fitted 	
Channels	Circular 	Square 	Elliptic 
Cut	Non 	Upper part 	Middle 
Attachment	Integrate 	Assemble same time 	Assemble after 
Material	Plastic	Aluminum	

Figure 8. The block – Morphology matrix

From these 324 different concepts, three concepts were selected from this morphological matrix that have most potential to free up space. The combination of sub-solutions for these three concepts is described below.

Concept 4 – The block:

The shape of this concept is a block with a simple thickness. The internals channels have circular shape where the block is built by two parts. The parts have the cut in the middle. The attachment of components on the block occurs after the composition of the block. Plastic will be the material.

Concept 5 – The Fork:

This concept has the shape as a fork, more suitable for its environment, where the thickness is more fitted. The channels has circular shape as in the block-concept where this block consist of two parts with a cut in the middle. The attachment for this concept is integrated in the block, for example O-ring seal on the spigot. The material for this concept is also plastic.

Concept 6 – The U-block:

The last concept that was created for this idea group is made in plastic material and has the shape of a U, which has been adapted to its environment, in this case around a pipe, for example. This concept has also circular channels, where the block consists of two parts with a cut in the middle. The attachment for components on this block is done in the same time as the block two parts are assembled.

For more description and visualization of the concepts, see Appendix 12

4.8.2. Morphological matrices – Result

By using the morphological matrices, several different concepts could be generated which is of great use for the project. Due to the timeframe for the project, it is not possible to evaluate the entire combination of solutions, since the number of different concept is very high. Instead, each sub-solution was evaluated in order to find the optimal combination of the different sub-solutions. Many of these sub-solutions were manufacturing related, and one of these will be the cheapest and easiest way to manufacture the product. By brainstorming and discussing within the authors, six concepts were created. Three concepts for each idea.

The six concepts that have been generated and selected from the morphological matrices were thereby further developed in order to create more specific and described concepts. These concepts have been named to, *wing*, *tube* and *snail*, which are concepts that fulfils the fan-shroud idea. The other ones have been named to *block*, *fork* and *U-block.*

4.9. Concept elimination

At the beginning of this stage, the number of remaining concepts were six where the aim after the execution of this stage was to end up with one concept for further investigation in the detailed design stage. To eliminate concepts and remain the best one, methods such as Pugh matrix and Kesselring matrix have been utilized. Pugh matrix have been used to screen out some of the concepts. In the end, Kesselring matrix come to use as a scoring matrix with the aim to select the best concept.

4.9.1. Pugh matrix

To be able to examine this matrix, several criteria were needed to be stated. A part that is worth to mention is that all these six concepts fulfils the requirements in the requirement list. With this in mind, the criteria that are stated in the matrix are a mix of both requirements and desires. As it can be seen in the matrix, there are ten criteria, in the left row (see Figure 9 below). To have the possibility to execute this matrix, a reference concept is necessary to select. One of the concept was chosen as reference concept, the block to be more specific.

The other concepts have been rated against the reference concept where the rate scale is better (+), equal (0) or worse (-). This procedure was repeated for each concept and criteria. In the end a summation of the (+), (0) and (-) were performed for each concept.

The result from this matrix is three concepts, from same idea group. These are the block, fork and the U-block, where these concepts will therefore be further evaluated in the Kesselring matrix. The other three are thereby eliminated at this stage.

Pugh matrix	**Concepts**					
Criterias	**Block (ref)**	**Fork**	**U-block**	**Wing**	**Tube**	**Snail**
Cost	0	-	-	-	0	-
Ease of manufacture	0	-	0	-	0	-
Ease of assembly	0	0	0	-	-	-
Easy to maintenance	0	0	0	0	0	0
Modularity	0	+	+	-	-	-
Number of parts	0	+	+	+	+	+
Perceived quality	0	0	0	0	0	-
Performance	0	0	0	+	+	-
Volume reduction	0	+	+	0	0	0
Weight	0	+	+	-	-	-
Sum +	0	4	4	2	2	1
Sum 0	10	4	5	3	5	2
Sum -	0	2	1	5	3	7
Concept score	0	2	3	-3	-1	-6
Rank	3	2	1	5	4	6
Continue?	Yes	Yes	Yes	No	No	No

Figure 9. Pugh matrix

4.9.2. Kesselring matrix

As mentioned in the previous section, the three concepts are needed to be reduced to one single concept. The Kesselring matrix with the same criteria as in the Pugh matrix was used to score and visualize how well the remaining concepts fulfil the criteria. The rating weight number is 1-5 where 5 indicates as most important. As it can be seen in the matrix the concepts Fork and Block have the highest total score, see Figure 10 below. The U-block with the lowest total score has brought that this concept has been eliminated. After the execution of this matrix, the two concepts Block and Fork were remained. To evaluate these concepts in a fast but correct way, a consultation with the supervisor at Volvo Cars and a senior technical expertise were utilized. This is more described in the section 4.9.3 Concept combination.

Kesselring matrix		Block		Fork		U-block	
Criterias	Weight	Value	Total	Value	Total	Value	Total
Cost	3	4	12	3	9	3	9
Ease of manufacture	4	4	16	3	12	3	12
Ease of assembly	4	3	12	4	16	3	12
Easy to maintenance	3	4	12	4	12	3	9
Modularity	2	2	4	3	6	3	6
Number of parts	3	3	9	4	12	2	6
Perceived quality	3	4	12	4	12	4	12
Performance	4	4	16	4	16	4	16
Volume reduction	5	4	20	5	25	3	15
Weight	2	2	4	4	8	4	8
Total score		117		128		105	
Rank		2		1		3	

Figure 10. Kesselring matrix

4.9.3. Concept combination

At this stage, a consultation with supervisor and senior technical expertise were set up in order to get feedback and advices regarding the concepts. Well analysed input from the supervisor and the expertise were added during the meeting. The result from this meeting was that none of these two concept should be eliminated. Instead, a combination of these concepts and create a new concept that consist the best properties from each concept would be more valuable.

This led to a new created concept with the name *The Blork* consisting of following sub-solutions.

- Shape as a fork but with a simple geometry
- Internal channels
- Integrated attachment for components and hoses
- None cut

The shape of this concept has the appearance as a fork, but with a simple geometry. The peaks on the forks are inputs and outputs to components connected to the block. This concept is made of plastic and has also internal channels where its spigots are integrated in the block. None cut is needed since the concept has no outer cover and instead consists of composite channels.

4.10. Detail design

As a product development process, detailed design transforms concept alternatives, preliminary physical architectures, design specifications, and technical requirements into final design definitions. The new concept Blork that has been created by combination of two concepts, has at this stage been further developed.

Computer Aided Design (CAD) program has been utilized in order to achieve the detailed design phase more efficient. Catia V5 has been used as a CAD-program because it is the standard program at Volvo Car Corporation and the authors have experience with the software.

The developed concept consist of a general concept that shows the benefits of having such a block to extract more volume. Since there will be modifications on the concept to apply it to specific areas.

The concept has internal channels where the shape is suited for its environment but still has a simple geometry since the manufacturing process is an essential part as well. Different components are attached on the block, but which components that is connected to the block differ depending on which area the block is attached. Since two areas have been predetermined for the concept, the components that are possible to connect to the block are EWP, separator, the thermostat and two valves. The development of the concept was an iterative process where ideas are tested, edited after consultation and tested again. The concept has been developed in Catia V5, thereby visualized and tested in TeamCenter in order to see if the concept was fitted in the environment.

4.10.1. Material choice

Due to the limitation in time for the thesis, the proposed concept will not be further described than concept level. A specific material will not be selected, rather a specific material group has been selected.

Since the design of the concept has been decided, the next part is to choose the right material group for the concept. This can be decided in two ways according to Lillemets (2009). One can decide material before choosing the manufacturing process for the concept, or either decide the manufacturing process in order to eliminate some materials that do not fit the process. In most cases the manufacturing process is already predetermined in the specifications of the product. For example the product should be developed by extrusion or injection molded due to the company that produces the product already have existing equipment.

The material for this concept have some criteria that need to be fulfilled. These criteria are:

- The material must be of any hardness
- Relatively good stiffness
- Low weight
- High formability
- Water resistant
- Low cost

With these criteria in mind and consultation by expertise, it resulted in materials such as aluminum and plastics. The final stage of the materials screening ended up in the group plastics since the low weight and cost were the contributing factors. Since the position for the concept is on the cold side of engine, the material do not need any high heat resistance which is also another factor why aluminum was eliminated. The exposed temperature for the concept are dependent on the coolants temperature, the climate, and the hot air inside the engine compartment.

4.10.2. Manufacturing processes

In today's industry exist several different manufacturing processes where these processes are suitable for different applications and materials, to have the ability to produce different products. For example it is hard to mill details with plastic as a material.

Since the material group have been selected in the previous section, plastics offer a wide range of applicable manufacturing methods fit differently for different purposes. The plastic group will thereby eliminate some of the available processes, the cutting processing as an example. The criteria for the manufacturing process are:

- Allow mass production
- Low cost
- High quality
- No need for after-treatment

To fulfil these criteria in a satisfied way, three manufacturing processes were selected as the best method to develop the concept. Thermoforming, injection moulding and friction welding.

Thermoforming:

Advantages:

- High in quality and have good durability as compared to the ones used in other methods.
- Good speed.
- Enable a wide range of custom-made products.
- All types of plastics can be used in this process, which is not the case with the other methods.
- Low cost (including the tools and process).

Disadvantages:

- Can give a waste of roughly 20% material.
- In this process, only one side of part is defined by the mold.

Injection molding:

Advantages:

- Fast production (high amount of produced parts per hour).
- Material flexibility.
- Low cost.
- Design flexibility.
- Low waste.

Disadvantages:

- High initial cost.
- Exist some part restriction.

Friction welding:

Advantages:

- Can produce high quality welds in a short cycle time.
- No filler metal is required and flux is not used.
- Easy to operate equipment.

Disadvantages:

- Process limited to angular and flat butt welds.
- Only used for smaller parts.

Both the thermoforming and injection molding are applicable methods for this concept but the method that will be recommended for this concept is the injection molding. The reason why this method was chosen is due to that this manufacturing is a well-proven process that already exist in Volvo Cars. This means that keeping same process for this concept may lead to that same sub-contractor that is responsible for this manufacturing process can be utilized. The advantage of this is stronger business ties between the subcontractor and Volvo, as well as reduced cost. These methods are a proposal from the authors, this means that the choice between these three methods will therefore be handed over to the Volvo Cars, where experts within this field will take the final decision.

4.11. Attachment between block-components

Since the block has internal channels where components are directly attached to, different attachment concepts have been generated by means of brainstorming and expert advices. A high number of different concepts on how to attach components to the block have been developed where some of these have been eliminated as well. Eight concept have been remained in order to use different method to evaluate and score the concepts see Appendix 13. Pugh matrix and Kesselring have been utilized as screening and scoring matrices here.

4.11.1. Pugh matrix – Attachment

To evaluate and reduce the number of remained concepts, Pugh method was used as a screening matrix. Nine criteria were set up in order to view which of the concepts fulfil the criteria better, worse or equal in comparison to the reference concept. One of the concepts were thereby used as a reference concept, the concept with name Pressure see Figure 11 below.

As in the first Pugh matrix in section 4.9.1, this matrix has three scale (+, 0,-) where the result is viewed in the Figure 11 below. Four concepts achieved the highest points where these have been chosen to be further evaluated in the Kesselring Matrix. The same number of concepts are thereby eliminated and will not be further investigated.

Pugh matrix	Concepts							
Criterias	**Pressure (ref)**	**Spring**	**Snap**	**Ball**	**Screw Joint**	**Quick Rel**	**Puzzle**	**Socket**
Number of parts	0	-	0	-	-	-	+	0
Cost	0	-	0	-	0	-	0	-
Ease of manufacture	0	0	0	0	+	-	0	-
Ease of assembly	0	0	+	+	0	+	+	0
Easy to disassemble	0	0	0	-	0	+	-	0
Stability	0	-	-	-	+	0	-	+
Volume	0	0	0	+	-	-	0	0
Sealing	0	-	-	-	+	0	-	+
Tolerance	0	-	-	-	+	+	-	-
Sum +	0	0	1	2	4	3	2	2
Sum 0	9	4	5	1	3	2	3	4
Sum -	0	5	3	6	2	4	4	3
Concept score	0	-5	-2	-4	2	-1	-2	-1
Rank	2	8	5	7	1	3	5	3
Continue?	Yes	No	No	No	Yes	Yes	No	Yes

Figure 11. Pugh matrix for the attachment concepts

4.11.2. Kesselring matrix – Attachment

Since it was four concepts remaining regarding how to attach components to the block, a reduction of the number of concepts was necessary and this was achieved by utilizing Kesselring matrix. Same criteria as in the Pugh matrix were used, with the difference that the criteria were weighted at this stage, depending on their importance see Figure 12. As in the first Kesselring in section 4.9.2, the scale is 1-5 which enable a more fair way to evaluate the concepts.

The result from this matrix is one single concept that achieved the highest rank in comparison to other concepts. The conclusion is that this concept has been chosen as the attachment method for the block, where some modification for this concept is necessary. Thus, the other concepts have been eliminated.

Kesselring matrix		**Pressure**		**Screw Joint**		**Quick Release**		**Socket**	
Criterias	**Weight**	**Value**	**Total**	**Value**	**Total**	**Value**	**Total**	**Value**	**Total**
Number of parts	3	3	9	4	12	3	9	5	15
Cost	3	4	12	4	12	3	9	2	6
Ease of manufacture	4	3	12	4	16	2	8	1	4
Ease of assembly	3	4	12	4	12	5	15	4	12
Easy to disassemble	2	4	8	4	8	5	10	4	8
Stability	4	3	12	5	20	4	16	5	20
Volume	2	4	8	3	6	4	8	5	10
Sealing	5	3	15	5	25	4	20	5	25
Tolerance	4	3	12	4	16	4	16	3	12
Total score		100		127		111		112	
Rank		4		1		3		2	

Figure 12. Kesselring matrix for the attachment concepts

5. Result

This chapter describes the result in the idea phase, concept phase, and detail phase. Ultimately, the final concept is visualized in a real environment, in an engine for this project.

5.1. Idea generation

During the idea phase, a high number of ideas were presented, where many of these ideas were eliminated. In the end of the idea generation, seven ideas remained. These ideas were evaluated by using a questionnaire survey, in which seven people from packing group and cooling group participated. The result of the survey was summarized in Table 4 where every idea obtained an average rating. The table is sorted from high to low scoring average.

The ideas that received the highest scores were selected for further development, in this case they are marked green in the table. The ideas that were not considered to have the greatest potential was thus eliminated, the red marked in the table. Two of the ideas (the yellow marked) was considered by respondents that they could be combined with the two top ideas. Both *change hose profile* and *attach components on inlet/outlet* can be combined with the *cooling block* and *components/hose in fan shroud*.

Table 4. Summary of the ideas with ratings

Idea name	***Rating (average)***
Cooling block	4,33
Change hose profile	3,67
Components/hose in fan shroud	3,5
Hose collectors	3,29
Cooling channels in components	3,21
Attach components on inlet/outlet	3,14
Air cooled components	2,42

5.2. Concept generation

During this phase, a concept was developed that met the requirements, produced in the early stage of this project. The concept that has been developed, belongs to idea group the block. This concept has been combined from two other concepts, which is more described in section 4.9.3 Concept combination.

The concept consists of a block with internal channels made for the transport of coolant that can be used in areas with many adjacent components, where the use of cooling hoses would otherwise result in increased volume usage. The channels in the block replaces the need for hoses between the components in question.

The advantage of internal channels in the block is that it can accommodate small turning radii, which is not possible with today cooling hoses. In areas where several components are connected together in a limited area, the hoses can occupy a lot of space which can be avoided by having a block with internal channels instead.

5.3. Detail design

The morphological matrix with sub-solutions and sub-functions generated six concepts, further reduced to three in a screening matrix. Finally preserved the one with the most points in a scoring matrix. Table 5 below shows the sub-solutions that the final concept consist of. The concept is made of plastic where the shape is fitted to its environment with internal channels that have circular shapes as already mentioned. The block has no cut since it can be created by using injection molding as a manufacturing process which is a process that enable complex geometry. Since the flange spigots on the block have angle, the attachment are thereby performed by friction welding for these spigots. This means that the block and its flange spigots are separated. The attachment between the block and components are made by means of flange joints that have been selected from the Kesselring matrix – Attachment in section 4.11.2. The reasons of using flange joints for this concept are:

- Much easier to seal
- Requires less tolerance
- Robust attachment
- Proven method which is used in the cooling system today.

Table 5. Description of the concept Blork

Morphological Matrix

Sub-function	Solution 1	Solution 2	Solution 3
Shape	Block	Fork	U-Block
Thickness	Simple	Fitted	
Channels	Circular	Square	Elliptic
Cut	Non	Upper part	Middle
Attachment block-components	Integrate	Assemble same time	Assemble after
Material	Aluminum	Plastic	

5.4. The Blork concept

The concept named the Blork consists of a solid plastic part with internal channels for transporting the coolant. The block also acts as the console through direct mounting of components, such as the EWP, the two valves, thermostat and/or separator. Cooling water can be transported between the components of the block channels, thus eliminating the need for hoses or pipe between them.

The Blork concept consist of two parts, the initial block and its spigots which are used as in/outlet. The manufacturing process for this concept is primary injection moulding since this process has high quality and good durability. High speed in addition to that it enable a wide range of customized products. The attachment between the block and its spigots with flanges can be achieved by using a suitable friction welding, such as spin welding or vibrational welding. The result by performing at this way is a block where two components are connected, the two valves, since the concept has been adapted to its environment, see Figure 13 and Figure 14. Notice that this is one suitable way of manufacturing the concept, there are others methods that can be applied as well.

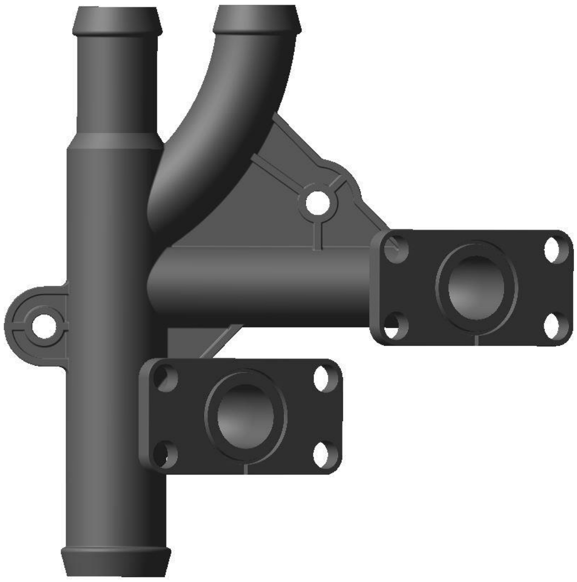


Figure 13. The Blork -front view

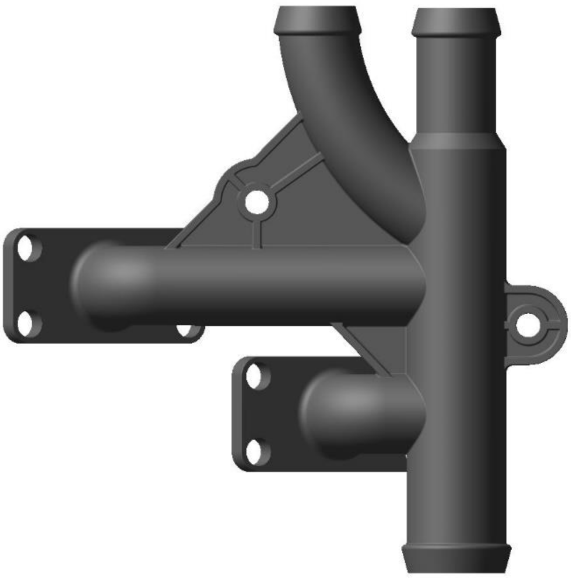


Figure 14. The Blork - back view

Figure 13 and Figure 14 shows also where the hole for its suspension of the block can be applied in its environment. Since the flat block contains no angles means that it becomes much easier to get it out of the mandrel. The red line in the figure (see Figure 15 below) indicates where the cut is for the spigots, meaning the place where the attachment between the block and its spigots with flange occurs. The joining method is friction welding where both spin rotation and vibrational welding are applicable at this case.

Figure 15. The Blork - Top view

5.4.1. Applied area

In order to optimize the shape of the concept and to illustrate its benefits, an area where the concept operating in was necessary to find. In the encircled area in the figure 16 below, the authors together with the supervisor at Volvo Cars through discussion, concluded that it is an area with great potential regarding the release of space. The current large bracket where two valves are fixed (see the red colored bracket in the encircled area) taking for the moment a lot of space combined with many unnecessary hose routings. This has been considered by the authors that this system can be optimized significantly through this concept.

One benefit for the concept in comparison to the bracket is that the concept occupy smaller area in the system, in comparison to the bracket. The components that are attached on the bracket, the two valves, are instead attached into the block. This lead thus to reduction in the hose routings which in turn leads to the concept frees up space for future components.

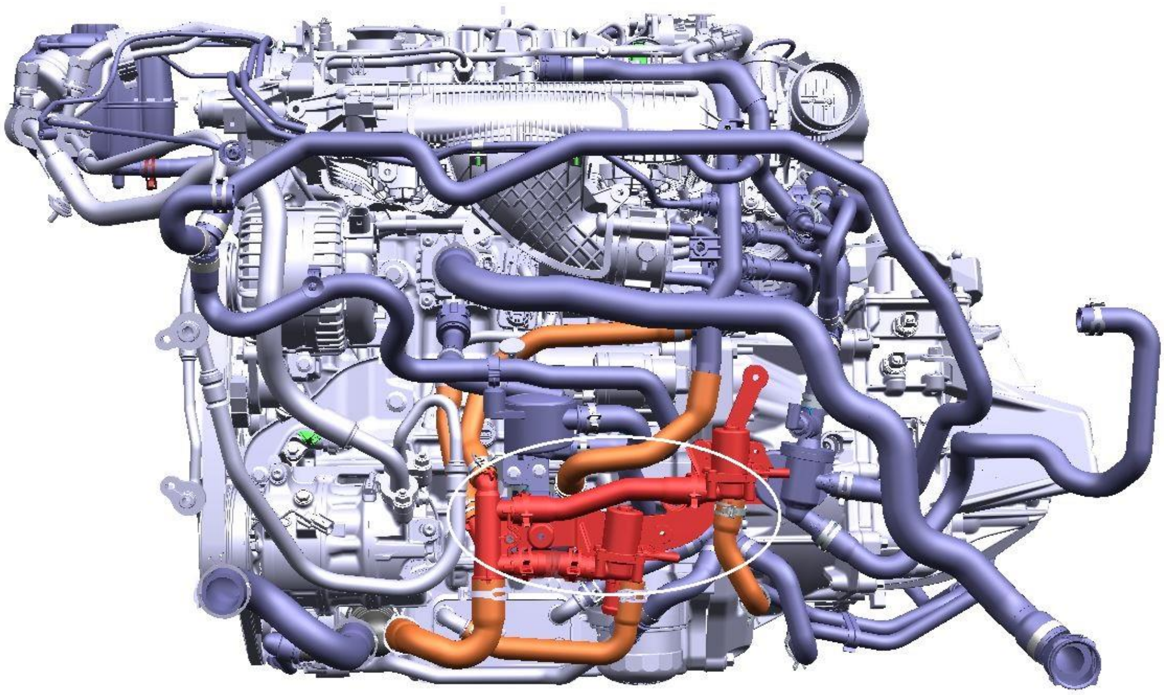


Figure 16. The applied area for the concept

5.4.2. Attachment of components

Now when the area where the concept will operate is determined, the components that are available within this area are the two valves. The two valves are meant to be directly mounted to the block as mentioned earlier. The attachment of the block will be performed by using flange joints, since flange joins was the method that achieved the highest ranking score in the Kesselring matrix in section 4.11.2. This block has spigots where the flanges are integrated. The spigots with the flange and the block are thus attached to each other by using friction welding as mention earlier.

To be able to perform the attachment between the components and block, it is necessary that the components also have flanges which is more described in next section 5.4.3. Modified components. When joining occurs, the flanges with four holes are pushed against each other where four screws are bolted. A part to mention is the O-ring rubber seal as well and benefits of using this, like higher tolerances and also locks the component in x y z etc. By executing in this way, a robust attachment will be achieved and a great sealing as well.

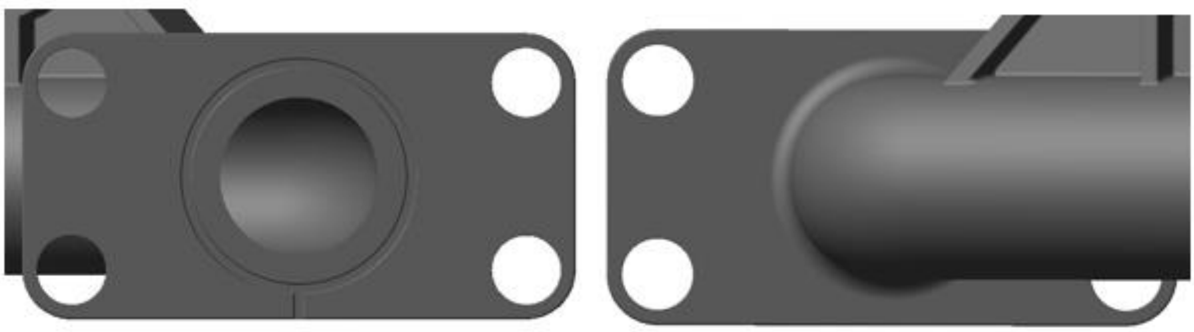


Figure 17. Flange joints with four holes for screwing

5.4.3. Modified components

Since the attachment of the components into the block is examined by using flange joints, it was necessary to modify the components. The standard attachment between concept and components has been determined to flange joints. The two valves needs thus a modification to be able to attach it to the block.

The modification for the valves is that the flanges have been integrated into the valves. In other words, the flange and valve are integrated into one single component see Figure 18 below. The benefit of performing at this way is that the manufacturing process for the valves with its attachment (flange) can be developed with one process and thereby delivered to Volvo Cars as complete units.

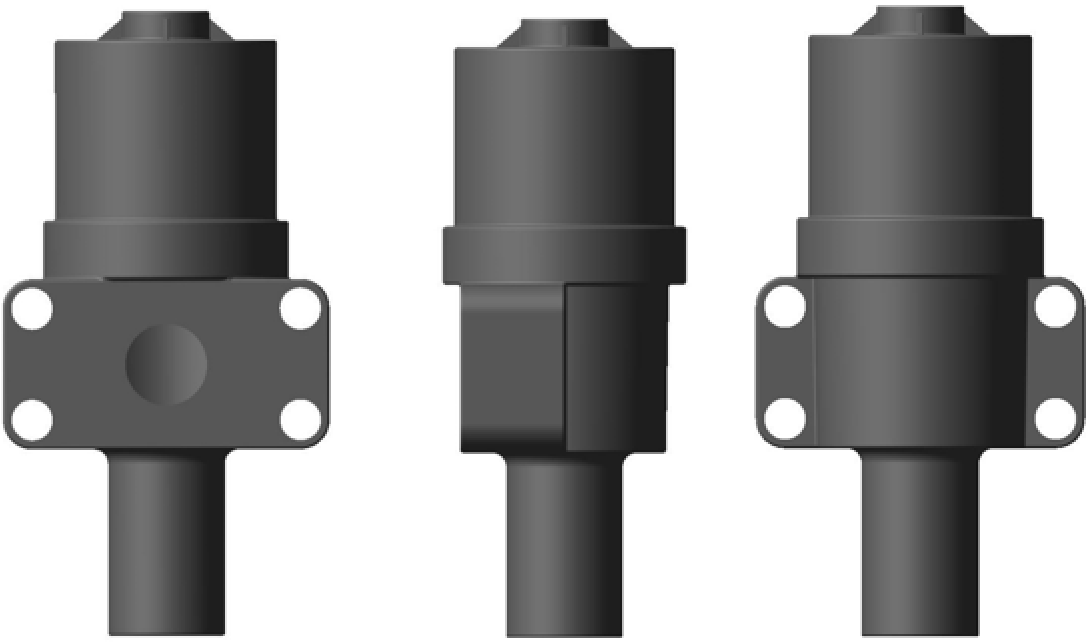


Figure 18. Modified valve

5.4.4. Weight reduction

As the weight reduction is essential for today's automotive industry was an overall weight calculation created. It compares the weights today's solution against the concept solution. The profits that can be made in weight is mainly to the amount of hoses and bracket that will be eliminated. As a result of this also the amount of coolant in the circuit is reduced. Table 6 below summarizes the estimated weights for the current and proposed solution.

Table 6. Estimated weight

	Current solution	The Blork	Difference
Components [g]	1452	928	524
Coolant weight [g]	246	107	139
Total [g]	1698	1035	663

In total, the concept of the proposed installation is to be about 0.6 kg lighter than the current solution. The estimates have some uncertainty when certain values are estimates and the total weight of the concept may increase. But in the end block is estimated to be slightly lighter than the current solution.

5.5. Installation in applied area

To demonstrate the concept's functionality and benefits, the Figure 19 below presented an application of the concept in the existing engine. The starting point has been to use existing components to help explain the concept.

When the concept with its components are fixed, it was time to apply it in the real environment which the block will operate within, in this case in an engine environment. The concept has been, as previously mentioned, partially adapted to the packing restrictions contained in the applicable field. However, the block need to be geometry secured in the earlier stage in the process in order to be used in real life but this is not discussed in this thesis, since this concept will be hand over to Volvo Cars in the concept stage.

In Figure 19 below, it shows the current solution for the existing engine where the red colored area is where this concept will operate within. As it can be seen in figure, the current solution occupy a lot of space where unnecessary hose routing exist, in combination with unused space that also can be used for future components.

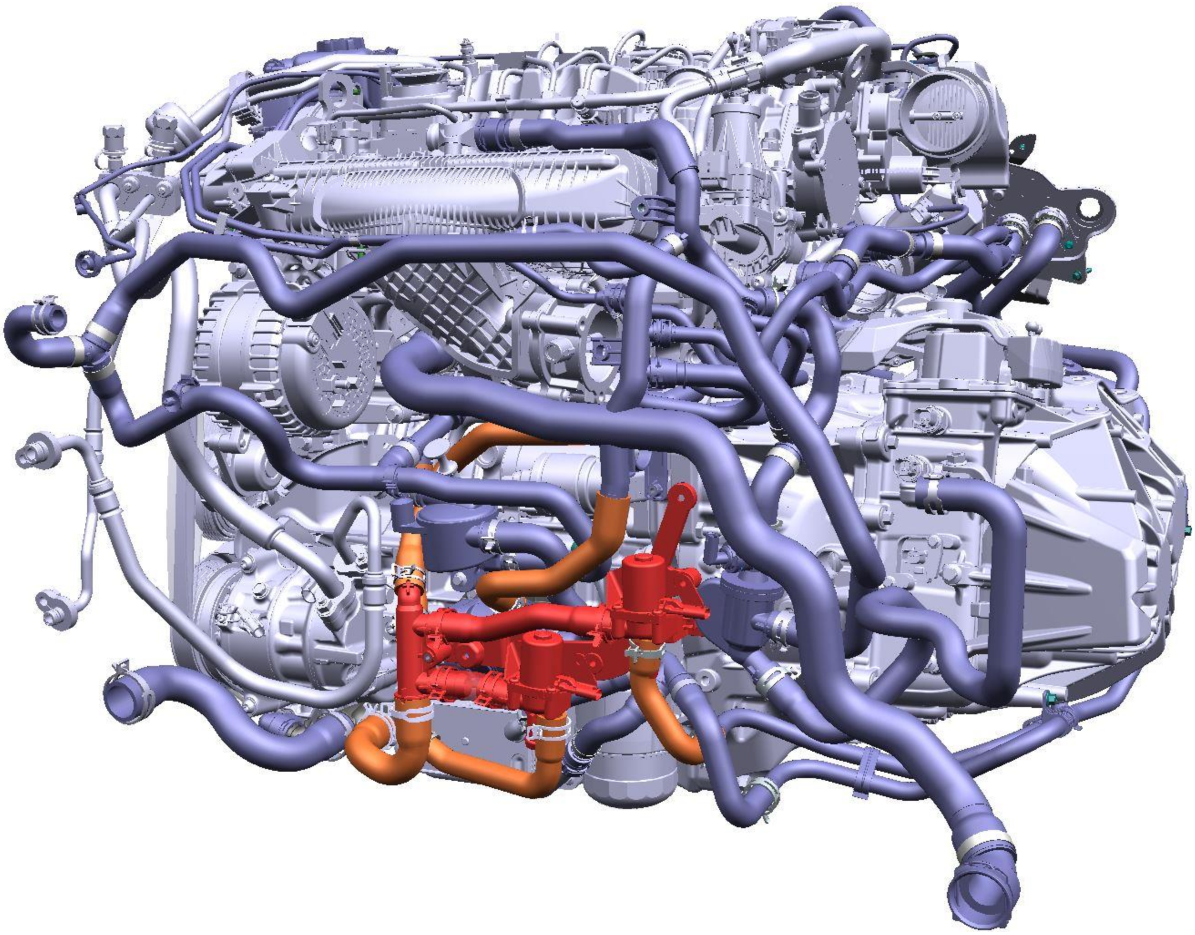


Figure 19. The current solution for VED

The red colored bracket is now instead replaced with the Blork in the Figure 20. This needed new hose routings to keep the functionality the same as today. The attachment between the Blork and hoses is performed by using the spigot with hose clamps, quick connector are also possible, which are solutions that exist in today's engine.

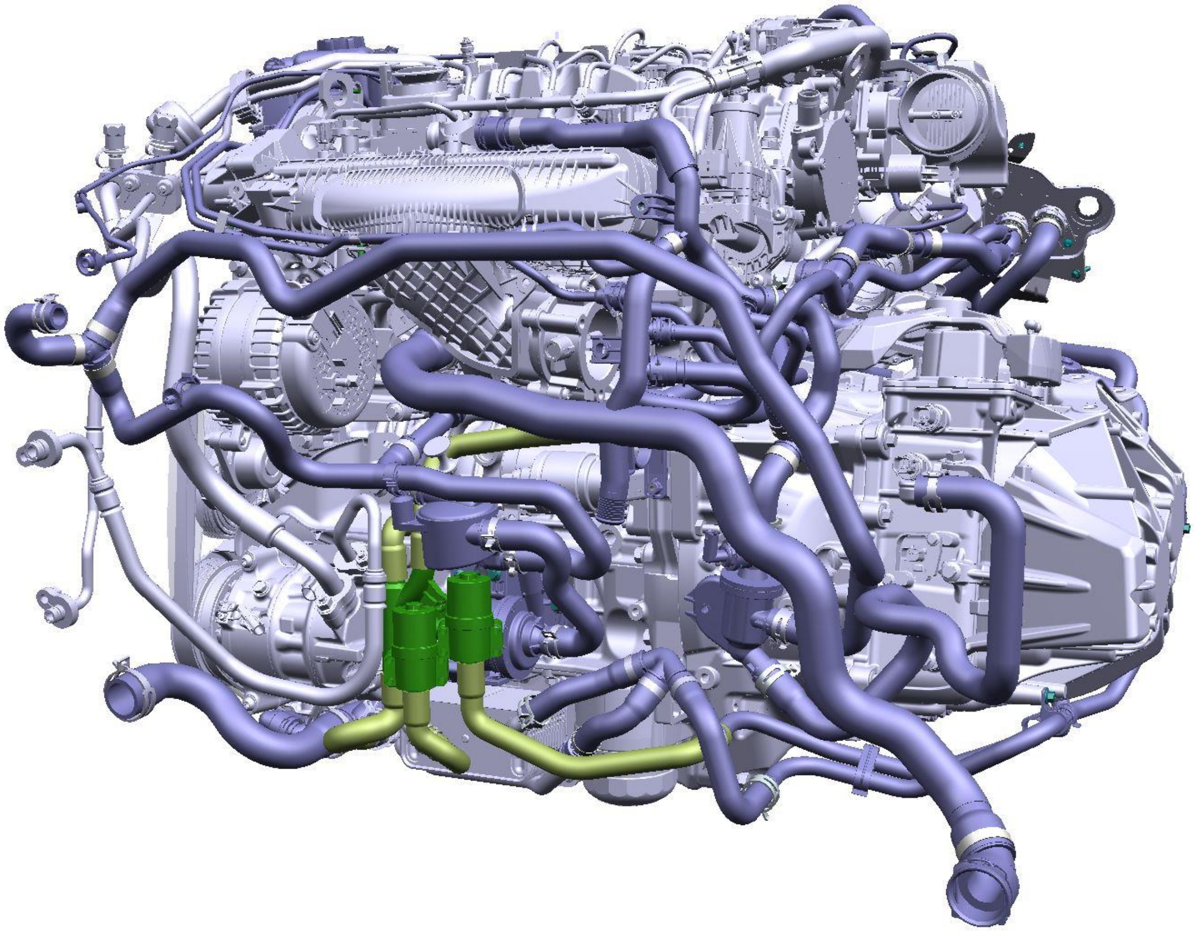


Figure 20. Blork applied in VED environment

To highlight the benefits of the block, a comparison is demonstrated in the two figures below, where the figures indicate today's solution versus solution the concept receives. As it can be seen the Blork enable much less space compared to the bracket (Figure 21). On the bracket where the two valves are mounted exist unused space between the valves which have been eliminated in the Blork concept. Instead, the valves are now tightly located to each other with direct attachment to the Blork.

Since the valves have been relocated in order to attach it to the concept, new hose routings were necessary. The most essential part was to keep the functionality at the same level at least, which means that no change in the flow chart was necessary. The result was fewer hose routings and less hoses in the system in comparison to the existing solution. Notice that the newly created hoses (dark blue) connected to the Blork are only for visualisation of the volume uptake and are not designed or routed after Volvo Cars standard.

Less hoses and more compact system have resulted that a lot of space has been freed up. The released space can now be used for other components for the future as the technology develops every day. New components and new technology in the engine compartment can be used to introduce new technical systems, which can provide more added value to the customer.

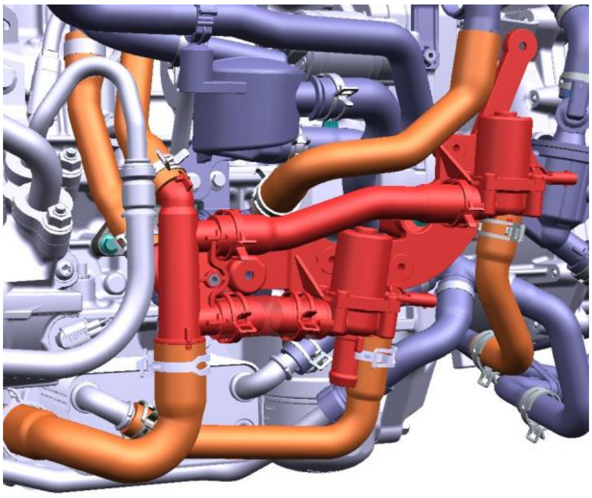


Figure 21. Today's solution for VED

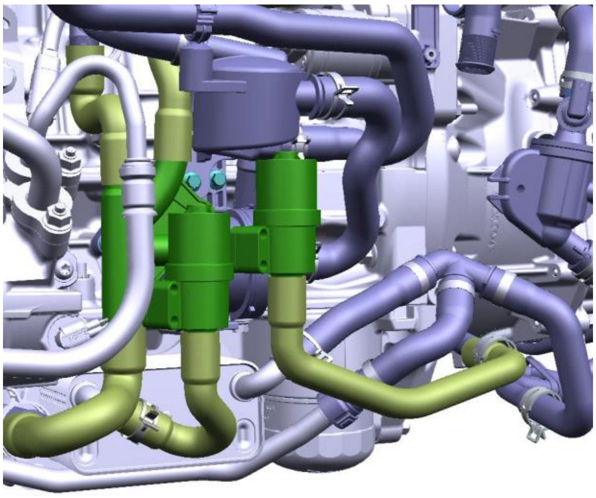


Figure 22. The solution the Blork receives for VED

5.6. Modular concept

One of the desires from Volvo Car Corporation, which is stated in the requirement list, was to make the concept modular. This means that the concept Blork can be adapted to other areas in the system to achieve more freed space. In order to operate in different areas for the Blork, its shape has to be modified to be able to adapt into its environment.

The essential benefit for this concept is that to have the ability to adapt it in different areas and thus create a bigger system that result in more freed up space. In section 5.6.1 Alternative area and 5.6.2. Alternative shape will describe more in detail.

5.6.1. Alternative area

An area where the concept Blork can be applied has been pointed out in the Figure 23 below. This area, as in the first applied, was concluded to have high potential regarding free up space since the authors, through discussion, realized that the components in this area also can be attached to the Blork. The components in question are the thermostat and separator that can be attached to the concept, since these components are located relative closed to each other.

The red colored bracket in the system can thus be eliminated and replaced by the concept that will have two different shapes in order to be adapt to its environment. This creates a bigger but more compact system in comparison to bracket system.

The result of having a modular concept is that the two areas can be applied for this concept with a modification in the shape. By executing it this way, two areas can be optimized significantly by using the modular concept. A part to notice is that the new created systems can be combined to one whole unit and thus make it more compact in order reduce the unused space that exist in today’s engine compartment.

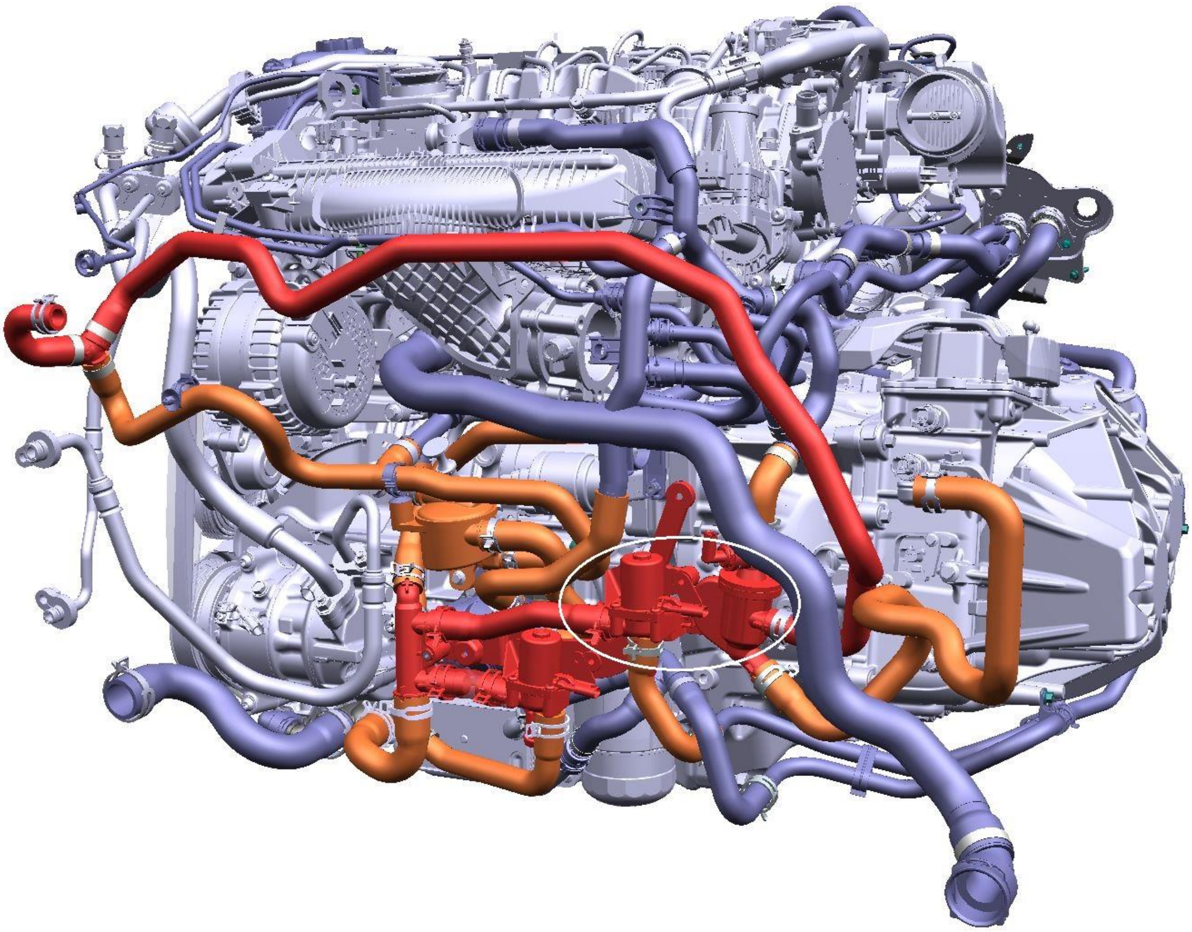


Figure 23. The new area where the modular concept can be applied

5.6.2. Alternative shape

Now when a new area has been determined, the concept has been modified in order to adapt it to its environment. As it can be seen in the Figure 23 above, the new area contains primarily the thermostat where this component are attached directly to the modified Blork. The new modified Blork has three in/outlet where one of those has a flange, see Figure 24 to the left. As for the first concept Blork, the attachment between the concept and its components is achieved by utilizing flanges with four holes.

The manufacturing process and the attachment between block and its flange spigot are the same as the initial concept. To be able to attach components on the block, in this case the thermostat, the components also needs to be modified.

The same procedure for the valves is also applied for the thermostat where the flange is integrated into thermostat as whole unit. By integrating the flange into the thermostat, a single component with one manufacturing process can be applied which will lead to lower cost.

As mentioned earlier, the two versions of the block can be combined to an entire system where the valves, thermostat and separator are connected see Appendix 15. By performing at this way achieves a significantly more compact system where unnecessary hose routing, hoses and unused spaces are eliminated. The drawback is that the combined system can be way to complex which can lead to that the manufacturing cost can increase.

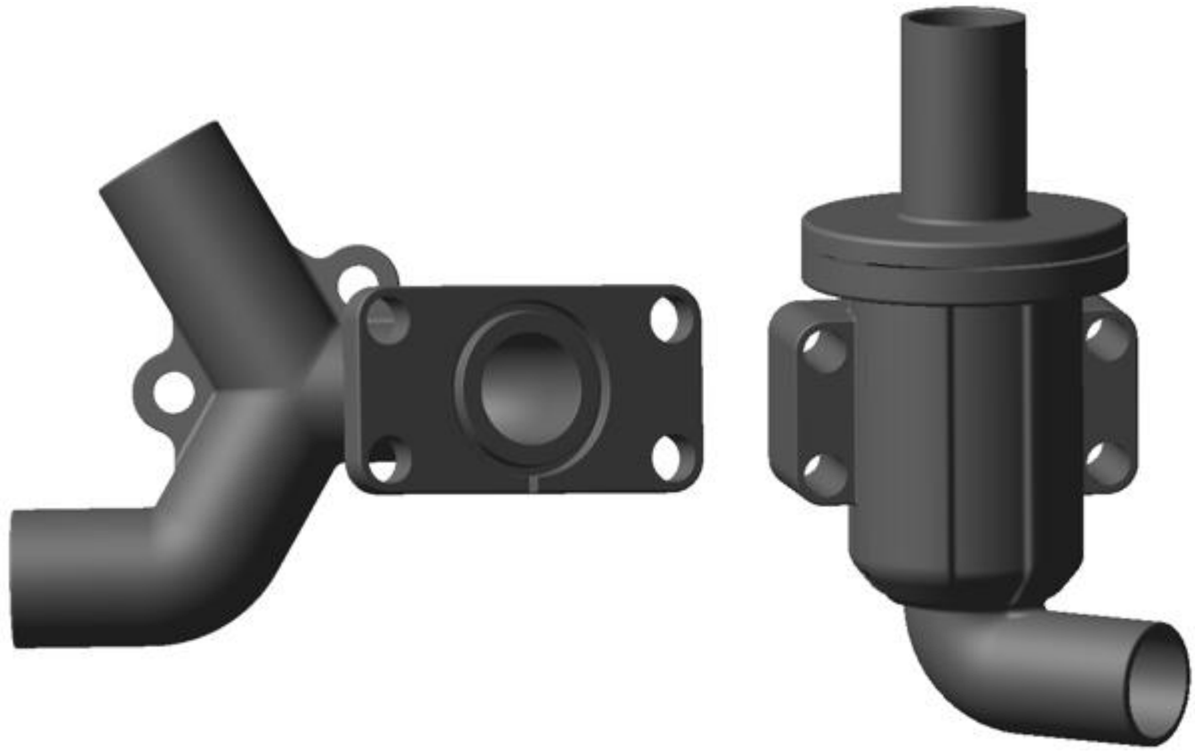


Figure 24. T.L The modified block with flange, T.R, The modified thermostat with flange

5.6.3. Alternative installation

The new concept applied in its area can now be seen in the Figure 25 below, where the both modification for the concept are applied in the system in order visualize the benefits of having two integrated system.

The second system has been connected to the separator and the thermostat as previous mentioned. The initial concept with the valves attached and the modified block have together created a bigger system that have resulted in a more frees up space for the future components, which was the aim for this concept. New hose routings were necessary to create in order to keep the current flow chart the same.

In the end, by using the initial concept in the system or the both concepts will however result in a more compact solution with less components in the system since hoses will be eliminated in both cases.

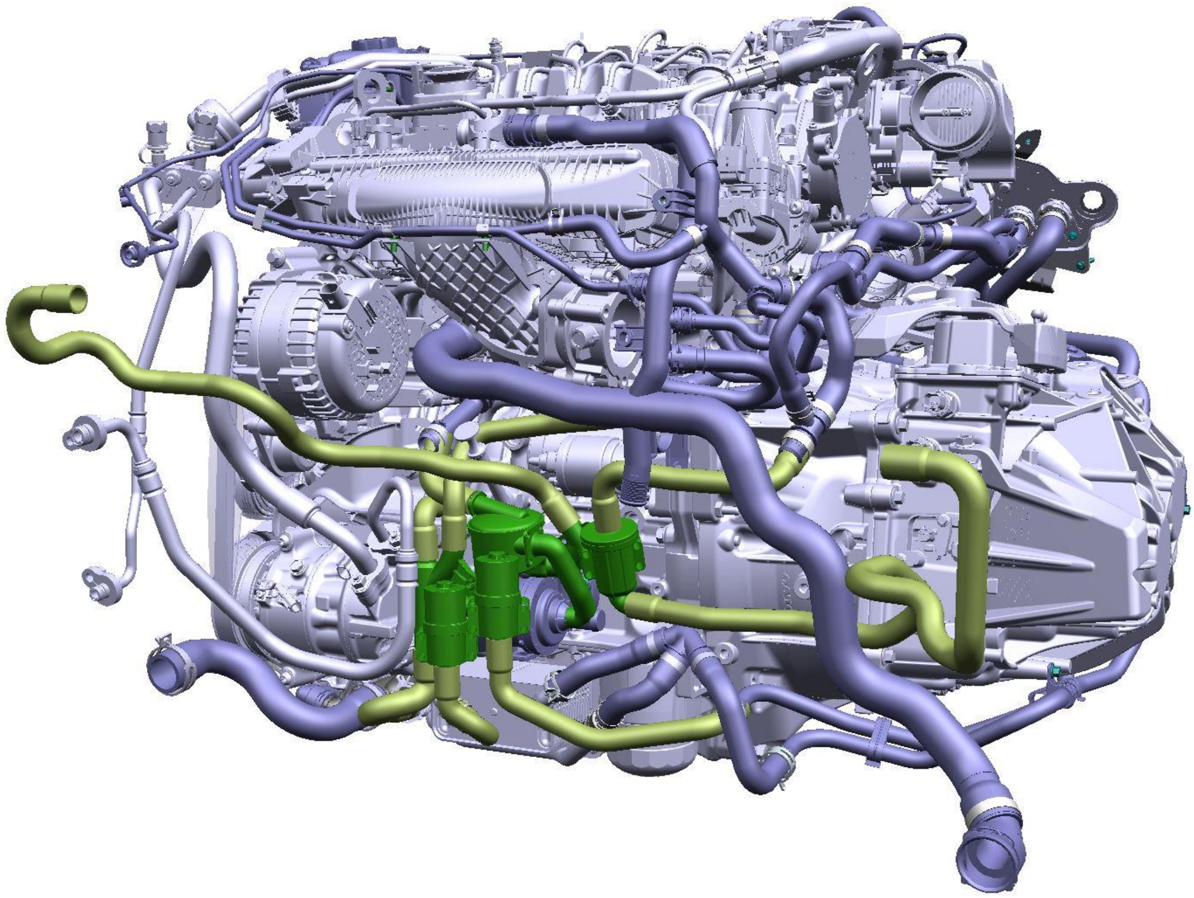


Figure 25. The initial and modified concept in an applied environment

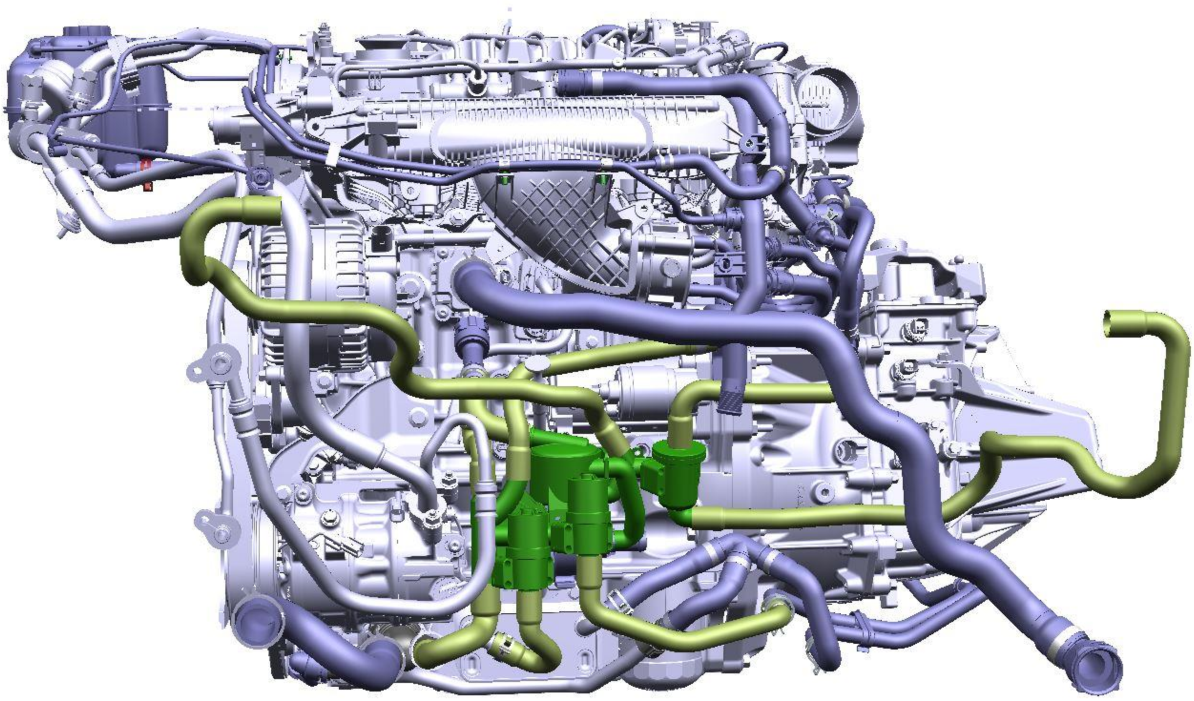


Figure 26. The large system

6. Method discussion

This chapter will discuss about the different methods that have been used during this project in order to achieve the result.

6.1. Pilot study

The pilot study was started with information regarding the cooling system. At the beginning of the study sought general knowledge of the system for its functionality, in order to subsequently immerse the authors in each component. It was hard to find depth information regarding each component, this led to that the entire system was studied more generally to get a good understanding of the entire system and its function. Questions that could not been found in Internet, were answered by the supervisor and technical expertise at Volvo Car Corporation during meetings. Types of questions that have been used during the interviews were both open and closed. Depending if the question is open or closed, different answers will be achieved. Open questions can provide more information than closed because they often lead to the person that will answer will provide a longer response that is reflective and well-reasoned. Closed questions have however a simple answer. A mixture of these types were hence very useful for this project since the authors needed expert advices.

6.2. Identification of customer needs

Ulrich & Eppinger (2012) mentioned that customer needs are generally expressed in the “language of the customer”. This means that product specifications should be establish early in the development process and then proceed to design and engineer the product to exactly meet those specifications. The product specification was already pre-determined for this project. In order words, no methods needed to be used for this step because the product requirements were already posted at the project start. Some modifications were created for the requirement list in order to refine and precise it and this was performed by interviews and consultation with the supervisor at Volvo Car Corporation. Ulrich & Eppinger (2012) also mentioned that the needs should be weighted depending of their importance, which have not been performed for this requirement list. The only difference that is shown in the list is which of the criteria that are requirements and which are desires see Appendix 2.

6.3. Benchmarking

The benchmarking was a useful tool for this project in order to gain more knowledge regarding the engine and cooling system. The website a2mac1 was a great source to gain a deeper knowledge regarding competitors cooling system and components. An observation was also conducted for two car brands in order to gain more knowledge about how different car manufactures work. Meanwhile benchmarking was conducted discovered that the competitors have very similar components and materials, which can be interpreted that the car industry work in a similar way. This meant that the benchmark does not give much input and hence benchmarking could have been carried out at another branch.

6.4. Brainstorming

To generate alternative solutions to the problems it is essential to think in new ways, hence the brainstorming is a good way to do this. This stage required more time than expected since the authors believed that the idea generation was a critical stage for the project, to generate ideas which have the highest potential to free up space. Below, some methods that have been used during the project will be discussed.

Mind maps:

Mind maps were used in order to start the brainstorming session and generate ideas and was a useful tool to connect information on a certain topic or subject. This method had some advantages that was useful for this project. A lot of ideas was created in a fast time due to the ease of creating shapes and arrows which allows refinement later on for example. The mind maps provide a great overview that helps to create a deeper understanding of the topic, which means that a great overview was provided for all related ideas, concepts and thoughts.

Lotus blossom technique:

The Lotus Blossom technique was a grateful tool to use in order to get in-depth knowledge regarding a topic. This procedure was performed twice. One occasion was performed by the authors, where the second round was conducted in conjunction with the group at the department. The reason why this method was performed in two different times, had the aim to achieve different point of view from the group.

The big advantage of this method was that it provides a balanced view of the ideas and their relationships. During the execution, one weakness was discovered for this method, it was hard to come up with 64 different ideas (8*8) which led to that many of the ideas could be applied on many places. The result was 64 ideas but not different ideas since a lot of the ideas were same or similar to each other. To be able to perform this technique in a correct way, it requires a lot of time since the number of ideas that are generated are high.

Contrariwise method:

The aim by using this method was to think in a different way. This method helps with a new line of thought when the participants can think of a way they are not accustomed to. The disadvantage of this method is that it does not always produce realistic solutions.

6-3-5 method:

6-3-5 method which stand for 6 participants, 3 ideas each within 5 minutes, is powerful tool since this method can provides a high number of well-analyzed ideas. Since this method was needed to be modified for this project due to the number of participants, was modified to 7-1-1. Meaning that seven participants, one idea each in one minute. This caused stress within the group due to time constraints which led to decreased quality of ideas. Better way to execute this method could have been increased time for each round, at the same time reduce the number of rounds.

6.5. Idea rating

To obtain experts' views and thoughts on the idea groups regarding their potential, the authors created a questionnaire, where each idea groups were described. A comment and a rating of 1-5 was required from each participant. In total, the questionnaire was sent to seven people from the departments packaging and cooling. This was a great way to get many views and thoughts from many different people at the same time, instead of setting up individual meeting for each participants, which had required a lot of time. On the other hand, to have individual interviews with the persons concerned had generated more information and input. In comparison with performing the questionnaire session, which was the drawback of using questionnaire. Another drawback was that there were some confusion for some involve people and they could not fully grasp the description of the idea and understand how the idea may look. Another thing was that some participants were way too specific and saw these ideas as a developed concept solution for the problem. With interviews this would have been avoided because the authors could describe the ideas and thoughts around them as well as explaining the current stage in the development process.

6.6. Concept generation

In the beginning of this stage, ideas have been reduced, eliminated, rated and finally two-three ideas have been selected. The aim for this stage was to generate concept that fulfils these ideas. The method morphological matrix has been utilized, two matrices to be more specific since the ideas had different sub-functions and thus different sub-solutions.

Morphological matrix:

Choosing a combination of sub-solution does not lead spontaneously to a solution to the overall problem which was something that the authors realized quickly. The combination of fragments must usually be developed and refined before an integrated solution emerges. But this tool allowed the authors to find possible solutions to complex problems characterised by several parameters which was of great use for this project. This matrix makes the developers to think about all the sub-functions for the concepts and forces a breakdown into smaller sub-solutions.

Important aspect to mention is that the morphological matrices was modified before performing the method. This, due to the morphological would generated too many concepts which would not been possible to evaluate each of them, since the project has timeframe to operate within. Instead, the sub-solutions become reduced to one or few for each sub-function, which led to the number of concepts that could be generated were significantly reduced. The disadvantage by doing it this way was that a lot of concepts that could have high potential become eliminated without any evaluation.

6.7. Concept elimination

To come to this stage, a variety of different methods have been utilized as described above, to generate and rate different ideas and concepts. To eliminate concepts and choose right one in a correct way, two methods have been performed. Pugh matrix and Kesselring matrix where the former is used as a screening matrix and latter is utilized as scoring matrix, in order to select the final concept. Typically at this stage, before performing the Pugh matrix and Kesselring, an elimination matrix is utilized. This matrix has not been executed for this project and instead, discussion within the authors has been performed. A set of requirements were utilized during the discussion in order to eliminate concepts that not fulfil the stated requirements. This way of eliminating concepts spared a lot of time instead of creating eliminating matrix. In addition to that, a consultation with the supervisor at Volvo Cars has also been executed in order to get their viewpoint as well.

Pugh matrix:

The Pugh matrix has provided a simple approach to take multiple factors into account in order to reach a decision. It would have been useful to perform two Pugh matrices during this process, one individually between authors and one together with the group at department to get an objective view. Because the drawback with this matrix is that it can be subjective since it is the team that decide if the concept is better or worse than the reference one. This means that if team have a favorite concept from the beginning, it can be very easy to underrate the other concepts in order to eliminate them.

Another problem with this matrix that occurred was that since the matrix has only three-point scale (+, 0, -), it was hard to find the balance between if the concept was better or equal in comparison to the reference concept, which is one of the benefits for the Kesselring matrix.

Kesselring matrix:

This matrix was used in order to increase the resolution to better differentiate among competing concepts. In this stage, the authors weighted the relative importance of the selection criteria and focused on more refined comparisons with respect to each criterion. This was the most essential benefit for this matrix in comparison to Pugh matrix. The concepts at this stage were much easier to differentiate since it was 1-5 point scale, this provided a more fair way to rate the concepts.

Even this matrix also has the drawback regarding the subjective point of view from the team. The concept that is the favourite can easily be overrated while the rest can be underrated by the team. This could also be avoided by performing the matrix two times, one between the authors and one with the group excluding the authors. By doing this way would provide different point of view and also visualize if the team and authors selected the same concept. But this way of thinking could not be performed due to time issue since the project has timeframe to operate within. The weighting of criteria can have a huge impact on the result as well, this could have been evaluated with a pair wise comparison to obtain a more precise rating. The matrix could have been made several times with different weightings to see how the result would be affected and to really evaluate the importance of different criteria.

6.8. Detail design

In the morphological matrix sub-solutions could be visualized which was a very useful tool to demonstrate the variation that the concept could assume. Detail design phase came to be relatively long phase where several iterations took place to constantly refine the concept by adding and revising existing partial solutions.

When a concept was chosen with the help of Kesselring matrix and consultation with experts at Volvo Cars and the supervisor, the next step in the process were to detail the concept, in order to refine it. The tools that have been used to create, refine and improve the concept were Catia V5 and TeamCenter. Catia V5 was used to create the concept, where the refinement and improvement were performed as well. TeamCenter came to a great use when applying the created concept in an assembly engine environment in order to visualize if the concept fulfil the requirements. These two tools were a central part of the detail design. To perform the iterations, Catia v5 was utilized to improve the concept and TeamCenter was the tool to utilize in order to verify if more iterations were necessary.

By using these two tools provided also great understanding and view of the created concept since it can be shown in a reality environment for the concept which increase the understanding to other concerned people within the department. The concept was also further developed in other ways than visualisation, to further support the concept and promote potential in many different aspects.

7. Result discussion

This chapter discuss the result achieved from the created concept, both the initial and the modular concept.

In order to discuss the entire result achieved in this master thesis, some points will be discussed through this chapter. The points that will be discussed are:

- Packaging and geometry assurance
- Preparation for manufacture
- Serviceability
- Attachment strategies
- Warehousing
- Advantages and drawbacks
- Modularity and flexibility
- Manufacturing

7.1. Packaging and geometry assurance

In today's situation, there are major problems in the engine compartment regarding packaging properties since it is too tight in the engine compartment which complicates packing and geometry assurance. The foremost benefit of the block is that it facilitates the compaction work through a lower volume uptake than the current solution, this is because the components are built together into a more tight, volume saving device. However, there are some ambiguities and disadvantages regarding if it gets easier when a large unit is applied instead of several smaller components, in terms of geometry assurance.

By visualizing the concept in the system TeamCenter shows that the concept is applicable. It is clear that a block as a unit need geometry assurance earlier in the product development process than the hoses, which today allowed changes in the late stages because of their simple geometries. Early in the process it appears that the rubber hoses have poor tolerances due to its elasticity. This problem is avoided significantly with a stiff block instead of multiple elastic hoses.

As technology develops further and more and more components are introduced in the engine compartment which results in less space. In such a mode, this block prove to be a useful design solution in challenging packaging situations. Another advantage of the block is that instead of only differ hoses routes or possibly a plastic tube, this block can be used as alternative construction.

In the current situation it exist in a low extent that the components are put together from different systems. With this block design as a construction base, such as electrical wiring, hoses, air hoses and components can be integrated. In the end, a block where more system components are integrated can be a start of increased cooperation between the schemes.

7.2. Preparation for manufacture

A block that is delivered pre-assembled from the sub-contractor probably has a relatively simple installation on the production line. The idea of this block regarding the preparation can be explained with the help of three steps. The plate block, its spigots with the flange and modified components with flange connections. The attachment between the block and its spigots with flanges occurs with a suitable frictional welding. The modified components with the flanges integrated are attached to the block with the flanges and screws. The benefit of executing at this way is that the block, its spigots with flanges and the modified components can either be pre-assembled from the sub-contractor and thereby be delivered to Volvo Cars as whole unit or be delivered to Volvo Cars as three single components where the attachment of the components to block occurs at Volvo Cars. Most likely the last sequence requires both less time and fewer errors than the current solution, mainly because the current solution contains many more components and assembly operations.

7.3. Serviceability

Serviceability of the cooling system depends very much on the position in the engine compartment. The components are easy to replace or service if the accessibility are good enough. However, there is a risk of leakage when the block channels are filled with coolant. Minor leakage is something that also happens today when the components are disassembled for service. It is of great importance that the attachment of the block and its components are accessible since the attachment and removal of the block should be easy to handle.

7.4. Attachment strategies

Different attachments are needed in order to hold the block on the engine and components on the block. The blocks shape gives a lot of opportunities and possibilities to create attachments to the engine by using screws. One of the harder aspects for the attachment is the accessibility, thereby the best way is to place the screws that it can be reached even with components attached to the block. Other possible attachments of the block to engine have not been evaluated because this design is used on most parts on the engine today.

The attachment of component to block have been evaluated by means of different methods and expert advisory. Many different solutions were evaluated and those who are used at Volvo Cars today is the screw flange and the O-ring sealing. However, the main reason for the flange selection is its high stability as well as high tolerances for the sealing. Compared to the O-ring sealing which requires some kind of fastener and has low tolerances. This means that two O-ring sealing's cannot be used for a component because it would be too hard to fit. However a combination of an O-ring sealing and a flange is possible.

7.5. Warehousing

An increased number of components also means increased complexity at the warehouse, increased number of shelves to hold the different parts. By eliminating parts and hoses in the block concept the storage will also require less time to handle and less variety in shelves to pick from. An example is the large block system which contains of 7 different components (screws and hose clamps excluded) compared to today's system with 11 components. On the other side it will be harder to stack the more complex block shapes than regular hoses.

7.6. Advantages and drawbacks

One of the foremost advantages of the block is the large volume of savings it receives. It is both smaller in size and contains fewer parts in comparison with the current solution that exists. Additionally, the block receives fixation of components on the block, which means that an entire system with several components can be created. This means, from a manufacturing point of view, the entire system can be supplied from subcontractors as a unit. Since components are attached to the block, the unused spaces that exist in the current solution are eliminated. The unused space that exist between the components in today's solution is due to the unnecessary hose routings. Thereby, the concept replaces the cooling hoses, components used for a very long time for the transport of coolant. The block has also lower weight in comparison to the bracket which is a great advantage since many cars are today front-loaded due to increased number of components.

The block does not only provides benefits to the packaging department, it also brings advantages to cooling department. Since cooling components are attached to block, leads to the components obtained fixed positions in the engine compartment.

The concept has not been tested physically and therefore it is unclear how well it works in practice. The concept's design has been developed through brainstorming, and in consultation with experts at Volvo Cars, which should ensure that the presented concept is good enough for further development. With extensive testing can block structure be modified if needed and its operation ensured. In addition to creating a new component and make it work, certain demands are put on the suppliers. Especially when the components that are currently part of the cooling system is expected to be modified to be attached to the block. The benefits of the concept becomes less if suppliers are unable or unwilling to deliver the desired component, this lead to different components need to be ordered from different suppliers which increases the cost.

7.7. Modularity and flexibility

One of the desires from Volvo Cars was that to create the concept in a modular way. This means that the created concept can be applied for different application with some modification. This concept has been created in such way that it can be applied in different areas in the engine compartment. Two areas have been pointed out in this thesis where this concept with some modification can be applied. The idea of making the concept modular, in this case having the ability to applied it in different areas, results in a more volume saving perspective. One either choose to have one shape applied in the system or have the both shapes in order to create a more complex system. The created complex system will thus provide a more frees up space, since the two created concept have been integrated into a whole system with different components attached.

Since the concept is modular in such way that it can be applied in different areas with some modification, leads to that the concepts are flexible. The opportunity for flexibility and customization of both current and future products continues to be determined largely by the manufacturing process as well as the choice of materials. The manufacturing process for this concept is injection moulding as mentioned earlier, which is a method that allows complex geometry can be created for this concept.

7.8. Manufacturing

The material plastic was chosen for this concept, meaning that an applicable manufacturing process was necessary to find. The injection molding was chosen in the end. This method is used to create many things such as wire spools, packaging, bottle caps, automotive parts and components. The cost for this method is essential, this means that the number of cavities incorporated into a mold will directly correlate in molding costs. Fewer cavities require far less tooling work, meaning that limiting the number of cavities in-turn will result in lower initial manufacturing costs to build an injection mold.

As the number of cavities play a vital role in molding costs, does the complexity of the part's design as well. Complexity can be incorporated into many factors such as surface finishing, tolerance requirements, internal or external threads, fine detailing. If the component does not need any further after treatment or has lower surface tolerances, the cost will thereby decrease.

8. Conclusion

This chapter presents the answers to the questions that were stated in the beginning of the process and indicates further studies can be conducted.

8.1. Answers to purpose and goal

- Is it possible to improve the geometry of the powertrain cooling system with maintained serviceability, functionality and product preparation?

The concept occupies a lower volume than the current solution and therefore benefits packing and geometry assurance. Because different components are directly mounted on the block results in additional space freed. The functionality will be the same as before, with the only difference that the new hose routings required for the new concept. If the concept can be supplied pre-assembled to the factory, the assembly is expected to be simpler and faster than the current solution. Serviceability is expected to at least be equivalent, since fixed components can be easily assembled and disassembled.

- Is it possible to improve the geometry of the powertrain cooling system with reduced cost, improved quality and/or increased ease of manufacture?

The concept is smaller in comparison to the current solution which means that less materials is required to create the concept. It also has quite simple shape which benefits the manufacturing process due to that complexity in the shape correlates with the cost. With these arguments in mind, less material, suitable manufacturing process which in this case is injection moulding and the complexity of the shape will result in reduced cost for the product. Simplified installation and inventory reduction are also factors that reduce the total cost. The quality assumes to be equivalent as the current solution but this area need more testing to assure the quality.

- Is the final concept innovative and involves new way of thinking?

In today's situation it does not exist any block solution that integrates different components into a system as this concept delivers. This block solution has internal channels with the ability to attach different components on it, depending on which area the concept is applied. This concept is also modular, meaning that with some modification, can it be adapt in different areas. With these points stated above, the concept is thus both innovative and includes a new way of thinking.

8.2. Recommendations

To be able to create and apply this concept in a real environment, some points below is needed to be more investigated.

- **Cost**: A detailed cost estimate must be developed.
- **Material selection**: Different materials must be investigated with the specific properties needed for the concepts application.
- **Calculations**: Flow calculations need to be created to ensure that the internal channels are capable of handling the flow pressure and no pressure drop occurs.

- **Testing and verifying**: Since the concept is ending up in a concept stage, meaning that no prototype will be conducted. Testing and verifying is necessary to execute in order to visualize if the concept fulfills the requirements in reality.
- **Manufacturing process**: In this thesis one manufacturing process was chosen for the concept. Other manufacturing processes that take into account the number of components to be manufactured, part complexity and material component, are needed to be investigated.

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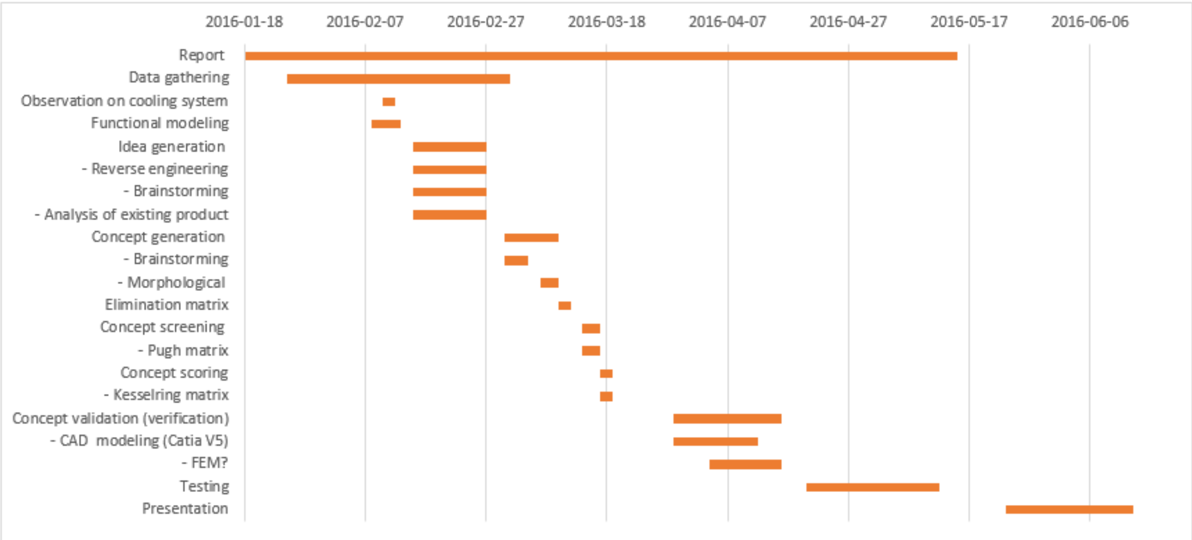
Appendix

Appendix 1

Gant schedule

GANT - Chart

Aktivitet	Start	Dagar	Stopp
Report	2016-01-18	118	2016-05-15
Data gathering	2016-01-25	37	2015-03-01
Observation on cooling system	2016-02-10	2	2016-02-12
Functional modeling	2016-02-08	5	2016-02-12
Idea generation	2016-02-15	12	2016-02-26
- Reverse engineering	2016-02-15	12	2016-02-26
- Brainstorming	2016-02-15	12	2016-02-26
- Analysis of existing product	2016-02-15	12	2016-02-26
Concept generation	2016-03-01	9	2016-03-09
- Brainstorming	2016-03-01	4	2016-03-04
- Morphological	2016-03-07	3	2016-03-09
Elimination matrix	2016-03-10	2	2016-03-11
Concept screening	2016-03-14	3	2016-03-16
- Pugh matrix	2016-03-14	3	2016-03-16
Concept scoring	2016-03-17	2	2016-03-18
- Kesselring matrix	2016-03-17	2	2016-03-18
Concept validation (verification)	2016-03-29	18	2016-04-15
- CAD modeling (Catia V5)	2016-03-29	14	2016-04-11
- FEM?	2016-04-04	12	2016-04-15
Testing	2016-04-20	22	2016-05-16
Presentation	2016-05-23	22	2016-06-13



Appendix 2

Requirement list

Requirement list

Customer needs	Requirement/Desire
Requires less space in comparison to current solution	Requirement
Cooling the system in a good way	Requirement
Easy to manufacture and assembly	Requirement
Easy to deassembly	Requirement
Has low cost	Desire
Easy to maintenance	Requirement
Can be applied to a number of car models.	Desire
Enviromently friendly	Desire
Reduction of number of components	Desire
Mass reduction	Desire

Product requirements	Requirement/Desire	Unit
Optimized packing - Changing the geometry	Requirement	m^3
Maintained serviceability/servicetime	Requirement	sec
Maintained functionality	Requirement	-
Maintained production preparation	Requirement	-
No leakage	Requirement	-
Cost reduction	Desire	SEK
Preserved lifetime	Requirement	years
Can handle temperature differences	Requirement	^0C
Must be capable of removing a portion of the heat generated in the combustion chamber	Requirement	%
Heat pick up by cooling system	Requirement	^0C
Heat release by cooling system	Requirement	^0C
Logistics (be able to stock in warehouse)	Desire	-
Modular structure	Desire	-

Appendix 3

Interview Stefan Sundemo 2016-02-15

- *How is the cooling system structured, which circuits does it consist of? (GenIII)*

Different components requires a certain temperature to be efficient. Engine and Engine oil requires a temperature on 80^{0}C - 100^{0}C, which is controlled by the hot cooling circuit. The cold cooling circuit goes to components which emits lower heat or that they can't handle to high temperatures, eg. WCAC. But if WCAC should be to cold, it would then create condensation inside the tank which leads to acid water and in worst case corrosion. The battery needs a temperature on 20^{0}C - 30^{0}C and cannot be exceeded, same thing goes for other electronics.

The climate system needs to be able to cool the cabin to a temperature both below and above the outside temperature.

- *Earlier improvements? How have the system developed?*

Additional circuits to be able to control temperatures, for an improved combustion and to make components even more effective.

HT EGR needs to be cooled before the compressor and the temperature for WCAC needs good control.

Additional components which have gradually increased, which means that hoses have been added gradually as well when needed, i.e. extension. The whole complex cooling system have not been evaluated, rather solutions for part systems have been made and just added to the system as the development proceeded.

- *Are there any holy components (do not touch!)?*

The water pump should be placed low to not risk that it only pumps air if a leakage have occurred, this would lead to engine failure. The radiator is over dimensioned so it can handle a leakage and a lower level of coolant but the engine cannot, it always need to be filled with coolant. This is secured by placing the water pump at a low position.

The thermostat have been installed at the inlet of the engine but gave lower results, so now it's always installed on the engine outlet.

The heater should be provided with as hot coolant as possible to not waste the energy.

The expansion tank should be placed high, so its level exceeds the engine and the proper coolant pressure is obtained.

Constant rising/slanting hoses to avoid that coolant, air or oil not get stuck. No hooks or hang on the hose that makes the flow to lose its continuity.

- *Where is the potential to free up space?*

Especially at the front of the engine, because there is many fixed components on the backside of the engine and not enough space for the cooling system. Another factor is that the emission system is localized in the back which is very warm, so cooling should not be close to this system.

One idea is to integrate hoses directly into the engine block instead of hoses to save space. E.g. EOC can be integrated from the pump to the oil cooler directly in the block, same thing could be applied for the bypass from the thermostat, EGR hoses, etc. Maybe heater hoses can be attached directly from the engine as close to the heater as possible.

- *Your own thoughts/experiences around the cooling system? General comments around the cooling system?*

Spend time in getting to know the system and dare to explore and try different ideas, in that way knowledge about the system, how the different circuits corporate and which cooling different components requires will be gained faster.

Appendix 4

Interview Torbjörn Andersson 2016-02-26

- *Which components or areas have been most troublesome regards packaging on GenIII?*

Cold engine side (front of the engine) which involves many big hoses. Compared to the previous engines GenIII have many added cooling components (e.g. WCAC).

GenI engine had 3 different installations, different platforms, C1MCA, SPA and EUCD. In the end of the development packaging had a lot of work to make it all possible to fit. The installation is easier on the GenIII as it only has 2 platforms. It was easy in the beginning of the GenIII engine. Water in and water out, then it was gradually added new circuits and components.

- *Where is the potential to free up space?*

- *Is there any changes in the cooling system that have been discussed but never been explored? Which and why?*

The hoses works just fine with rubber (EPDM) and are cheap, compared to plastic and metal which requires bending process because lack of flexibility. The attachment of the hoses are clamps or a quick coupling. The clamps are cheaper but occupies more space, the more expensive quick coupling is becoming more and more used as it's required from the assembly.

- *Is there any changes in the cooling system that have been examined but failed? Which and why?*

The idea from the earlier thesis work on the cooling system got stuck in the Ratio (a process which is cost evaluating).

Another idea was to integrate hoses in the engine block, but it would have a significant increase in manufacturing cost and require a new casting process. Another aspect was that it would be hard to control the coolant when it's running in the engine, would the coolant become too hot or would it cool the engine to much?

- *How much freed up space is desired for the next generation?*

With no flow losses, as tight and small as possible.

- *Why is both a mechanical and an electric pump used?*

The mechanical pump is driven from the engine and needs to be placed at the belt, where the space is limited. The electric pumps is expensive and big, the pump for the cold circuit needs less power than the warm circuit, so if the mechanical pump would be replaced with and electrical it would have been much bigger. However a benefit with an electric water pump is that it can still be used when the engine have stopped.

- *The valve and the thermostat have similar functions except the valve doesn't have a bypass system. The valve is used for e.g. EOC and TOC, doesn't it need a continuous flow of coolant in the same way as the engine and the cold circuit system?*

The EOC and TOC don't have the hot spots like the engine and don't need a continuous flow in the same way, so no bypass system is needed.

- *Your own thoughts/experiences around the cooling system? General comments around the cooling system from a packaging viewpoint?*

Grotesquely complex, it saves fuel but will not be able to continue with additional extension. The cooling system is reaching its limit regarding packaging and the space it requires. The development have always have the highest prioritising on the engine, so the surrounding components have to adjust to the engine. The hoses are made late in the development because they are flexible, “it can always be solved”.

The cooling system have don't kept up with the other parts of the powertrain. The biggest problem with regards to packaging is all the hoses, as a consequence of all the additional components.

Another interesting idea for this project is to look at other industries that involves cooling systems. For example, excavators, airplanes, aerospace and so forth.

Appendix 5

Lotus blossom technique - individual

Relocate generator	EWP between generator and AC compressor	Move components to the thermostat	Hose + hose	Separator + EWP	Valve+ valve	Change the flow	Through engine block	Cooling trough car body
Components around transmission	Relocate components	Hug engine	Separator + thermostat	Integrate components	Valve + hose	Underneath the engine	Alternative way of hoses	Cooling through the hood
Cooling on engine back side	Structure hoses	Move starter motor	Hose + engine block	Components + in/outlet	Expansion tank + engine	Behind engine	Squeeze engine	Around the transmission
Soft materials in hose	Metal pipes	Plastic	Relocate components	Integrate components	Alternative way of hoses	Combine pump and EWP	Combine radiator and fan	Combine EOC and TOC
Textile (fire hose)	Alternative materials	Rubber	Alternative materials	Free up space	Combination of funktions	Air cooled components	Combination of funktions	Components /hose in the fan package
Plexiglass (transparant)	Ceramics	Composite materials	Eliminate components	Redesign components	Increase efficiency of the cooling system	Combine hose and pipe	Cooling in hoses (cooling component)	Use AC to the cooling system
Elimination of hoses (integration)	Separator	Valve	Reduce volume on pump	Reduce volume on seperator	More but smaller parallel hoses O ooo	Increase efficiency of the pump	Increase efficiency of the cooling flow	Increase efficiency of the radiator
Eliminate hose (additional rad. not in front)	Eliminate components	EWP (use pressure or mech. pump)	Reduce volume on radiator/ fan package	Redesign components	Change hose profile	Increase efficiency of the heat transfer	Increase efficiency of the cooling system	Central cooling-distributor
Reduce coolant flows	Combine cold- and hot circuit	Branching (integrate)	Reduce diameter and lenght of hose	Change thermo-stat (distribution of flow)	Components on engine (integrate /fasteners)	Cool fluid in the system (not only the front rad.)	Use the space behind the generator	Central cold- and hot circuit hose

Appendix 6

Contrariwise method

Contrariwise method

How do we make the cooling system as useless as possible? (With respect to the requirement list)

- Components as big as possible
- Small channels/hose
- Unstructured hoses
- Inaccessible for service
- Uncontrolled coolant flow
- Low efficiency in the pump (slow coolant flow)
- Low heat transfer in the radiator
- Leakage in the system
- No pressure equalization
- Air in the cooling system

Translate the negative to positive

- Compact components with maintained performance
- Optimal diameter for desired coolant flow
- Smart and structured hoses (shortest way)
- Easy for service to replace and examine components
- Use components that regulates and controls the coolant flow (eg. valve, sensors, etc.)
- Suitable coolant flow from the pump
- Enough heat transfer from the radiator
- Closed system, if leakage would occur, it should be easy to identify
- Constant pressure in the system with help of a pressure regulator
- Component which releases air from the system

Appendix 7

Lotus blossom technique – Group execution

<u>Free up space</u>

Part 1 – Individual

- Integrate cooling channels in the component.
- Integrate cooling channels between the components.
- Merging components.
- Increase airflow to the component + no need for additional cooling.
- Place the components for its natural flow.
- Other material.
- Other coolant.

- Eliminate.
- Relocate.
- Combine/integrate.
- Optimize.
- Minimize.
- Minimum road for hoses.
- Make more effective.
- Cross-functional.

- Stripe the hoses.
- Find new materials.
- Use quick release.
- Use Velcro tape for joining.
- Melt together the hoses.
- Find a smaller unit (cooling system).
- Find new suppliers.
- Building common consoles.

- One coolant to all cooling.
- Drag hoses shorter route.
- Merge hoses to like “highway with more files”.
- Merge cooling liquid of the same temperature range in the same hose.
- Further development of Philip & Anders “box”.
- Better ventilation and air flow through the engine compartment → more air intakes.

- Replace with components that do not need cooling.
- Eliminate rubber hoses.
- Integrate hose components into each other.
- Eliminate components that need cooling.
- Change to more efficient coolant.
- Optimize lay-out of powertrain.
- Cool directly with air.
- Optimize the engine space for heat dissipation.

- Position the components in close connection.
- In and outlet in same direction.
- Cooling-rug.
- Use pipe.

- Inner and outer hose in one.
- Hard articles on the engine.
- Larger branching point.
- Channels in the solid components, e.g. engine block.

Part 2 – In group

Place the components for its natural flow

- Redesign the engine.
- Organize – shortest route.
- Separate self-flow system.

Integrate cooling channels in the component

- Integrate into plastic components.
- Metal-Metal that need cooling.
- Components that need cooling "docked" in the engine block.
- "Cooling-hub" where components that need cooling are attached.

Integrate

- Hose – Hose/ Pipe – Pipe.
- Inner and outer hose in one.
- "Cooling-rug".
- Integrate cast components.
- Hose in the body, side member, sub-frame.
- Eliminate hoses.
- Make it modular → Build the cooling system in one and assembly it in the engine.

Optimize

- Minimize the necessary gap between the hoses.
- Change the shape of the hoses.
- Change the flow → higher pressure – smaller hose.
- One coolant for many places.
- Use requirement places.

Appendix 8

Group idea generation – execution – 6-3-5 method

1. Put together several hoses with stripe.
   - Squeeze the adjacent hoses → Reduces the gap → more space.

2. Put together all the valves to a "cake" and mount it on the engine.
   - Each part is a piece of cake → modular structure.
     - Assemble the Lego pieces or locks with sprinter.
       - Make thin walls in Lego.

3. Find out the requirements for the coldest need for cooling and use the coldest coolant in the brine to all cooling.
   - Examine other coolants.

   Using hoses that emit heat on the hot side of the component.
   - Move to the heat-collecting component.

4. Part-integrate the cooling in the engine → “Half channels with cover on”.
   - Use giant console (CB) in the middle to transport coolant or using other components.

   Add cooling hoses with “slide clips”. (Attached with Velcro).
   Separate cooling by area.

5. Use Velcro
   - Cross-functional: Assemble the components and avoid chafing.
   - Components need no gap between each other.
   - Can you be outside the claims surfaces in any way?
   - Cables being completely enclosed in the material adhering to each other.
   - Assemble as many hoses as possible, close together.

6. A large cooling block that collect as many hoses and other components as possible.
   - Increase flow pressure - smaller tube diameter needed.
   - Make parts of the block in the composite, such as carbon fiber.
   - Milled hydraulic block.

7. Another coolant
   - Recycle energy using new coolant.
   - New material in cooling hoses to deal with the new coolant and can withstand higher heat.
   - Efficient heat exchange where needed.

Appendix 9

Idea elimination

The ideas that remains after the first elimination with Stefan Sundemo and Torbjörn Andersson 2016-03-14

Red = +, Yellow = ++, Green = +++, Blue =? (=need more information)

Relocate components

1. ~~Relocate generator (make space for cooling components) +~~
2. ~~Move EWP between generator and AC compressor (and cooling components to the thermostat housing) ++~~
3. ~~Move LT rad +~~
4. ~~Components squeeze engine (thermal insulation between if it’s too hot?) ++~~
5. ~~Use requirement places?~~

Coolant flow

6. ~~Structure hoses (shortest way) +++~~
7. ~~Place components for its natural flow ++~~
8. ~~Reduce coolant flow (flow in series, not parallel) ++~~
9. ~~In and outlet in same direction (--->O--->) Example! ?~~

Air cooling

10. ~~Increased air outlet (air flow through engine compartment, hood and car body) +++~~
11. Air cooled components ++

Eliminate/replace components

12. ~~Elimination of hoses (integration) +++~~

Alternative materials

13. ~~Metal pipes ++~~
14. ~~Plastic ++~~
15. ~~Rubber +~~
16. ~~Ceramics +~~

Redesign components

17. Change hose profile (enable stacking) +++

Increase efficiency

18. ~~Hoses emit heat on hot side of component (outlet) +~~
19. ~~Transfer the heat from the coolant to other energy?~~

Integrate components

20. ~~Separator + EWP ++~~
21. ~~Valve + valve +TA~~
22. ~~Valve + hose Example! ?~~
23. Components + in/outlet (e.g. valve in EOC) ++

24. ~~Components + thermostat housing ++~~
25. Components/hose in the fan package (LT rad hose trough HT rad) ++
26. Cooling channels in components +++
27. ~~Combine EOC and TOC ?~~

Integrate in engine

28. ~~Hose + engine block (complete channels in block) Examine! ?~~
29. ~~Hose + engine block (half channels with cover, possible with branching in cover or complete channels) +~~
30. ~~Components on engine (integrate like water pump) ++~~

New components

31. Hose collector (gather hoses, stripes, Velcro tape, melt, 2 hoses in one) +++
32. ~~Central cooling distributor (sprinkler, one or several) +~~
33. Cooling block (collect hoses and components) ++
34. ~~Cooling rug (I≡I) ++~~

35. ~~Radiator in/outlet on the right side?~~
36. ~~Generator + MWP~~

Appendix 10

Idea rating

Air cooled components

Description

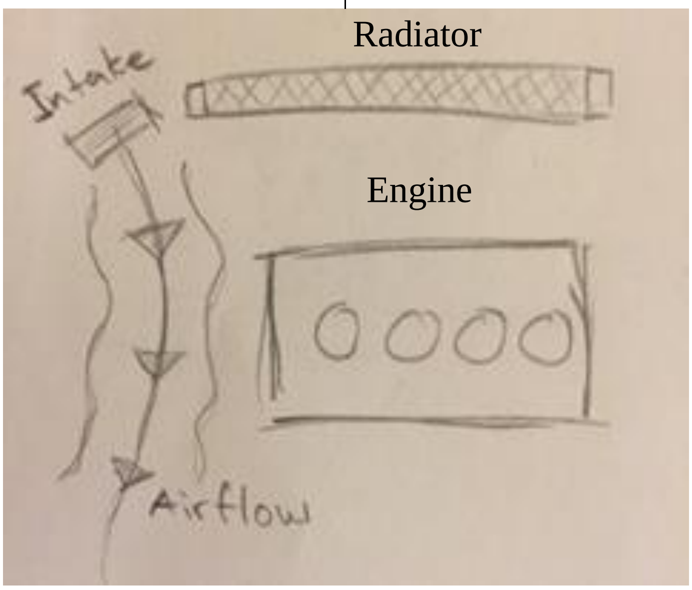
The idea is to use an additional airflow through the engine compartment. The airflow should be directed to cool components that doesn't generate too much heat. By using air to cool components, hoses can be eliminated from the water cooling system and replaced with an air flow.

Pros

- Eliminating hoses
- No need for coolant
- Possible to cool several components

Cons

- Pressure in engine compartment
- Hard to control
- No cooling while the vehicle is not moving



Comment

Idea rating 1-5:

Attach components on inlet/outlet

Description

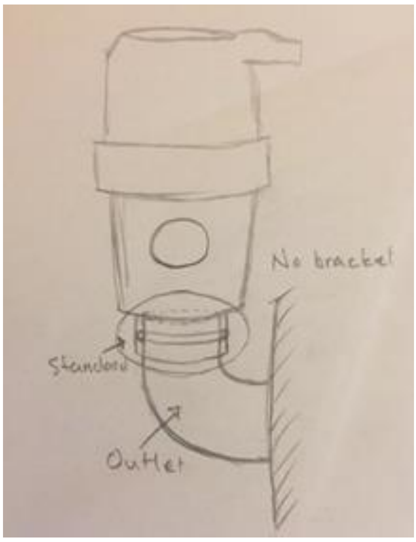
Placing components of the cooling system on the inlet or outlet of a component that requires cooling. This can enable a standardised interface and an easy attachment of the component. As the inlet/outlet are made by a more stiff material then the hose, the component may not need a fastener bracket. An example is to attach the valve on the outlet of the engine oil cooler.

Pros

- Eliminating hoses
- Eliminating brackets
- Standardised interface
- Possibilities with branching in inlet/outlet

Cons

- Not to heavy components
- Different suppliers have to standardise their components
- Varying diameter of the hoses attached to inlet/outlet today



Comment

Idea rating 1-5:

Change hose profile

Description

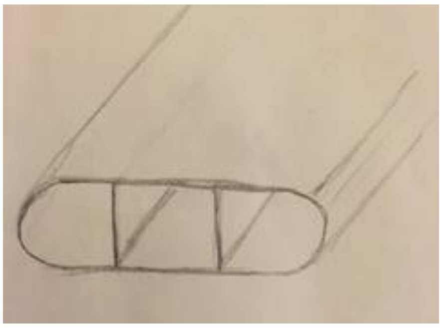
The hose profile is an important feature to take into consideration when optimizing the profiles since it can result in release of the space and more compact product will be achieved. With varying cross section, for example circular or square, the product can be packed in a more volume-efficient manner. A hose with a square profile enable better packaging and stacking properties in comparison to a hose with circular profile. But on the other hand should be consistent about the disadvantages of hoses with square profiles. Possibilities with multiple channels inside one hose.

Pros

- Eliminating hoses
- Better stacking properties
- Multiple channels

Cons

- A hose with a square profile in the corner where it is no radius
- The flow may be affected?



Comment

Idea rating 1-5:

Cooling block

Description

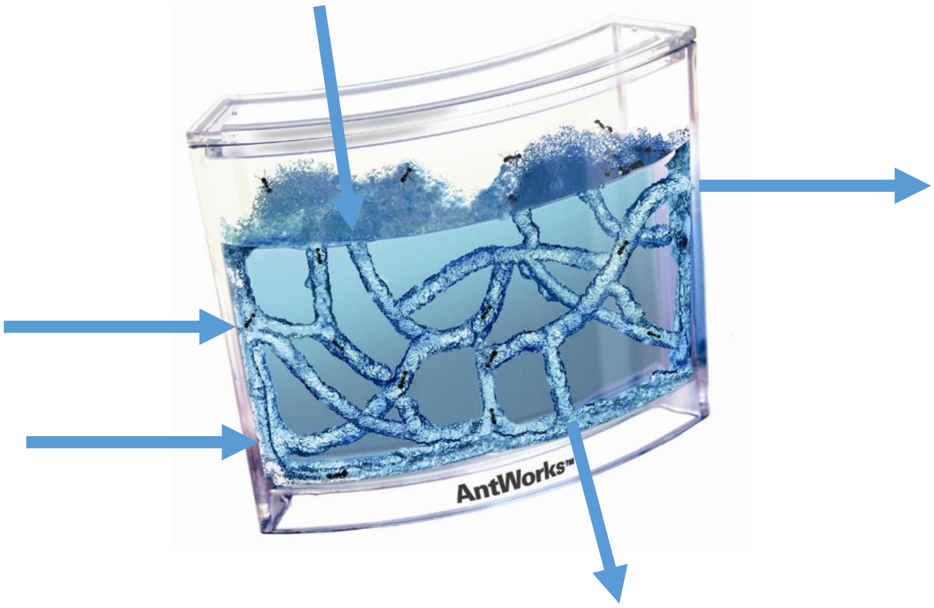
This idea is based on components and hoses that are closely packed will instead be integrated and attached to a block. The function of the block is to gather hoses and components to a more compact solution.

Pros

- Eliminating hoses
- Structure the hoses
- Compact system

Cons

- Complexity
- Temperature mix when channels are closely packed (heat convection)



Comment

Idea rating 1-5:

Components/hose in fan package

Description

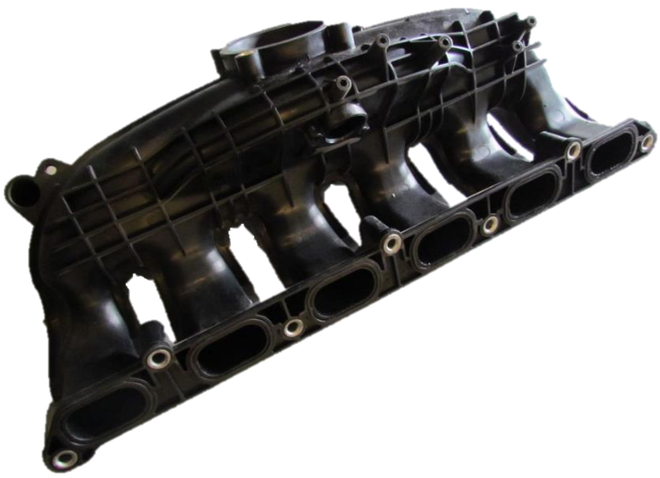
Using the fan package to make the radiator hoses to travel a smarter way to the engine. There is possibilities to mould water channels in the fan package which can transport and distribute water to the radiator tubes. The radiator side tanks could then be made smaller and the radiator can be expanded. Other possibilities with channels in the fan package is that the coolant could be precooled before it enters the radiator.

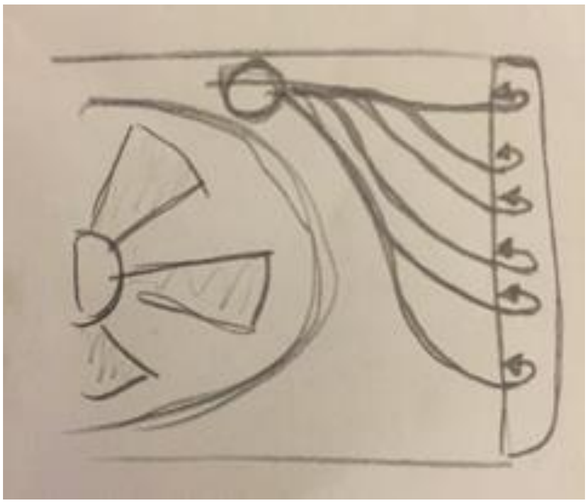
Pros

- Less hoses on engine cold side
- Smaller radiator tanks → larger radiator
- Precooled right before entering radiator

Cons

- Can only shorten and structure the radiator hoses
- Complex fan console
- Rearranging air flaps





Comment

Idea rating 1-5:

Cooling channels in components

Description

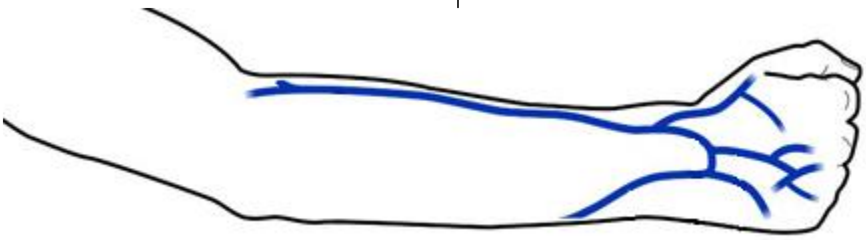
This idea is based on that some components will have channels that transport coolant. These channels in or trough components will replace hoses. An example of a channel is from the ETM to the WCAC where the coolant could travel through the intake manifold.

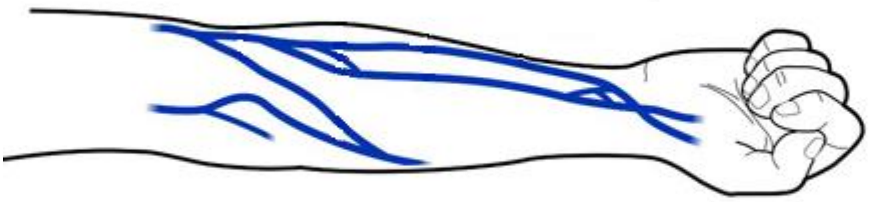
Pros

- Eliminating hoses
- Possible to connect channels to components in the cooling system

Cons

- Hard to control the temperature
- Transport channels should not affect the coolant in temperature
- If leakage occur the whole component may need to be replaced





Comment

Idea rating 1-5:

Hose collectors

Description

Hose collector can be used as a way to structure the hoses. This can be done in several ways as illustrated in pictures below by using different gatherers or collectors. It can also eliminate hoses by inserting hoses into each other, one larger hose with a smaller one inside.

Pros

- Eliminating hoses
- The hoses will be structured
- Better packing properties

Cons

- Hard to control the heat convection when it is two hoses in to one
- By the collection of several hoses can lead to one or more huge hoses
- Wear on hoses if they scuff against each other

Comment

Idea rating 1-5:

Appendix 11

Idea rating – Answers from the participants

Air cooled components

“We agree. This is the first choice for all designs, we don’t use water cooled before it is needed. AL Thermal is responsible for air cooled parts.” – AL

“The Engine Bay is hot and if the particular part might need air guides. If the guides come from the front of vehicle generally air hoses takes more room then a cooling hose.
If no genius transportation routing for cooling air this I believe is very difficult.” – TA

“Could be used for el.control units?” – SSU

”Kan kombineras med andra lösningar, men ej huvudlösning.” – MV

”Grill shutter är ett stort minus.
Om flödet ska vara riktat mot enskilda komponenter krävs ett rör, med större diameter än motsvarande för kylvatten. Kanske en bläckfisk med riktade luftrör hade varit något?
Många komponenter kräver ju bara lite kylning (Typ throttlar, EGR-ventil mm), dessa hade säkert klarat sig utmärkt med enbart luftkylning om de fick ett större luftflöde.
Vilka komponenter klarar sig utan kylning vid stillastående?
Idén är god, men känns tuff att få riktigt effektiv.” - FS

”Trevlig ide men spontant svårt att genomföra och i
varmt klimat ser jag inte att luftkylning räcker.” – PM

”Svårt att beräkna luftfödet. Hur funkar det i Varma länder?” – CE

	AL	*TA*	*SSU*	*MV*	*FS*	*PM*	*CE*	*TOT*
Rating	-	1	3	3	3	1,5	3	2,42

Attach components on inlet/outlet

“Ok but for heavier designs a screw joint is needed.” – AL

“The hose diameter will increase. Heat loss to cool pipe.
On the upside the visual complexity and assembly may be improved.” – TA

“Cost opportunity
Maybe less flexibility?” – SSU

“Kan vara svårt att påverka leverantörer att standardisera om vi inte har andra med, andra biltillverkare.” – MV

”Förstår inte den högra bilden. Politik kan ställa till detta, varför ska jag förstärka min komponent för att kyl ska fästa sin ventil där? Varianter kan skapa bekymmer, då antalet ventiler etc. varierar beroende på växellådsalternativ mm. I dessa fall skulle interfacet behöva vara samma för komponenten i båda fallen, med och utan ventil. Om det finns varianter utan, är det värt att förstärka komponenten för alla varianter.” – FS

”Det här är bra. Men vill veta mer om de standardiserade interfacen och den enkla fastsättningen av "komponenter.” – PM

”Kan bli dyrt och svårt att föra in. men ändå en bra tanke om det alltid finns fasta positioner” - CE

	AL	*TA*	*SSU*	*MV*	*FS*	*PM*	*CE*	*TOT*
Rating	5	2	3	2	3	4	3	3,14

Change hose profile

“A hose won’t stay any other shape than round when pressure is added
in plastic it is possible to keep the shape but the possibility to take up the movement between the parts is limited.” – AL

“Has potential to save space. Will probably be expensive. The lower picture shows a proposal that may work. A square cornered hose has a potential to blow up.” – TA

“Design and production process needs to be developed, in order to make the shape stiff enough vs inside pressure. Probably more efficient for low flows and small diameters. Picture with internal reinforcement wall could be working well, but probably more expensive.” – SSU

”Om man ändrar tvärsnittet så måste man öka i en annan ledd, för att få flödet, behålla arean. Kan vara bra ändå ifall man kan koppla ihop olika slangar och bara och öka i viss riktning, clipsa ihop.” – MV

”Är det ens tekniskt möjligt (till en försvarbar cost) att göra slangar med andra tvärsnitt? De måste vara förstärkta för att inte bli cirkulärt formade när man trycksätter dem.
Jag tror det är billigare och lättare att göra detta med plaströr, där man kan forma profilen precis som man vill i tajta områden.” – FS

”Ett intressant koncept men det finns anledning till att saker är runda. Om trycket inte är ett problem är det mycket intressant.” – PM

“Gillar…” - CE

	AL	*TA*	*SSU*	*MV*	*FS*	*PM*	*CE*	*TOT*
Rating	-	4	4	3	4	3	4	3,67

Cooling block

"The solution is interesting, but how will you do it?
Creating channels in a block that aren't straight is complicated
and I would need to see an example." – AL

"Probably one of the best solutions when it comes to packaging I think. Temperature mix can partly be helped by choice of material and insulating holes in the block." – TA

"Could have a significant potential, but engine block and cylinder head needs to be redesigned to fit." – SSU

"Spännande. Kan man ha som en kabelkanal som håller ihop slangarna, men att man har spår man trycker i slangarna i?" – MV

"Det klassiska hydraulik-blocket. Detta kan även fungera som konsol till de ventiler etc. som behöver en konsol. Här känns det mer lämpligt att lägga till tidigare koncept "attached components" då kyl kommer äga båda artiklarna.
Detta är riktigt bra i områden där många slangar ska ta stora böjar, i Gen3 framförallt kall sida och bakkant vxl. För kylsystem borde denna komponent kunna vara gjuten i plast, vilket skulle göra den ganska billig och isolerande för temp-skillnader. Kanske ha två separata, en för kallt vatten och en för varmt?!" – FS

"Som ett kretskort! Så här tänkte vi också under vårt exjobb. Iden är 1% → genomförandet är 99%. Kombinera med "attach components"?" – PM

"Kan vara en bra lösning men också väldigt komplex. Man kanske ska göra mindre enheter som kan återanvändas mellan de olika motorerna/varianterna." - CE

	AL	*TA*	*SSU*	*MV*	*FS*	*PM*	*CE*	*TOT*
Rating	-	5	4	3	5	5	4	4,33

<u>Components/hose in fan shroud</u>

"How would you create the channels in a shroud? A 2 part shroud? Water cores?
Need to understand the idea better.
I don't understand how you would connect the shroud coolant to the radiator end tank- I need some more information" – AL

"Solution limited by speed flaps on Cooling Fan. Has potential but may increase cost. Is the additional weight OK?" – TA

"Exiting idea, fan shroud will be somewhat more complex, but radiator hoses could be significantly simpler." – SSU

"Intressant tanke. Även om det är enbart radiator hose, så kan de leda till att skapa utrymme" – MV

"Detta ger främst möjlighet att ta ut vattnet på ett lämpligt ställe för slangen som ska ta motorrörelse till vattenpump etc. Känns som det kan påverka kostnaden för fläktkåpan mer än man tjänar på själva lösningen. Tveksam till det där med förkylning, tror det har marginell påverkan, givetvis beroende på hur det skulle se ut." – FS

"Lite förvirrad och ser inte riktigt potentialen." – PM

"Kan bli en förkylningsstation…men känns dyrt" - CE

	AL	*TA*	*SSU*	*MV*	*FS*	*PM*	*CE*	*TOT*
Rating	-	5	5	4	3	1	3	3,5

Cooling channels in components

“Channels in the component is very interesting. The usual issue is how it can be done- water/gas core, loose part and so one it is hard to judge specific ideas with an idea how to do it.” – AL

“Probably one of the best solutions for packaging but risk of high cost and reduced functionality. Plastic components should be much better adapted for this solution then a metal part due to conductivity.” – TA

“Sensitive, may be costly for customer/service” – SSU

”Känns dyrt. Vad är skillnaden mot att fästa sig i artiken?” – MV

”För detta känns det nästan som att de komponenter som ändå behöver kylning kan leda vattnet vidare till nästa komponent som också behöver kylning. De som sitter i serie och behöver kylning kan ju leda vattnet till varandra. Då gör det ju dessutom inget om transportkanalen avger värme då komponenten ändå ska ha kylning.
Era cons vill ja kritisera lite också:
Transportkanal kan vara samma sak som kylkanal.
Känns som att risken för läck är mindre om man inte har några externa kylkanaler, ofta bara en packning som behöver bytas.” – FS

”Visa mig hur ni tänker detta.” - PM

”Kan skapa bra med plats men man måste kanske ta fram
nya komponenter till varje projekt. Dyrt…” - CE

	AL	*TA*	*SSU*	*MV*	*FS*	*PM*	*CE*	*TOT*
Rating	5	4	2	2	5	1,5	3	3,21

<u>Hose collectors</u>

“This is similar to electric department’s cable channels, it could work well depending on how it is done. One issue is the hose sizes vs cables there will be a lot of dead space in the channel, the total diameter will be very large compared to the hoses that will be transported.” – AL

“May be difficult when hoses are separated in space, but has potential where hoses are packed very tight and it is possible to route them parallel.” – TA

“Hoses will be protected from outside. Needs hose connections on engine and in vehicle to be adapted. Probably less straps will be needed to fix hoses.” – SSU

“Borde kunna funka. Kanske inte på allt, men kan skapa utrymme.” – MV

”Ofta är det lättare att packa två små slangar än en stor, däremot tror jag det är en stor fördel att samla dem som ett cluster. Att de sitter tillsammans med tydlig styrning. Konceptet med nollspel mellan slangarna har ju för och nackdelar.
En tanke om man vill lägga dem i en stam, ha en kall och en varm stam, precis som det fungerar i kroppen, så slipper ni värmeutbytet.” – FS

”Ja detta vore effektivt men slangar ska till olika platser och en “highway” är lättare I teorin än I praktiken.” – PM

”Bra ide men kräver kanske att man tittar på andra material för att isolera och undvika skav” - CE

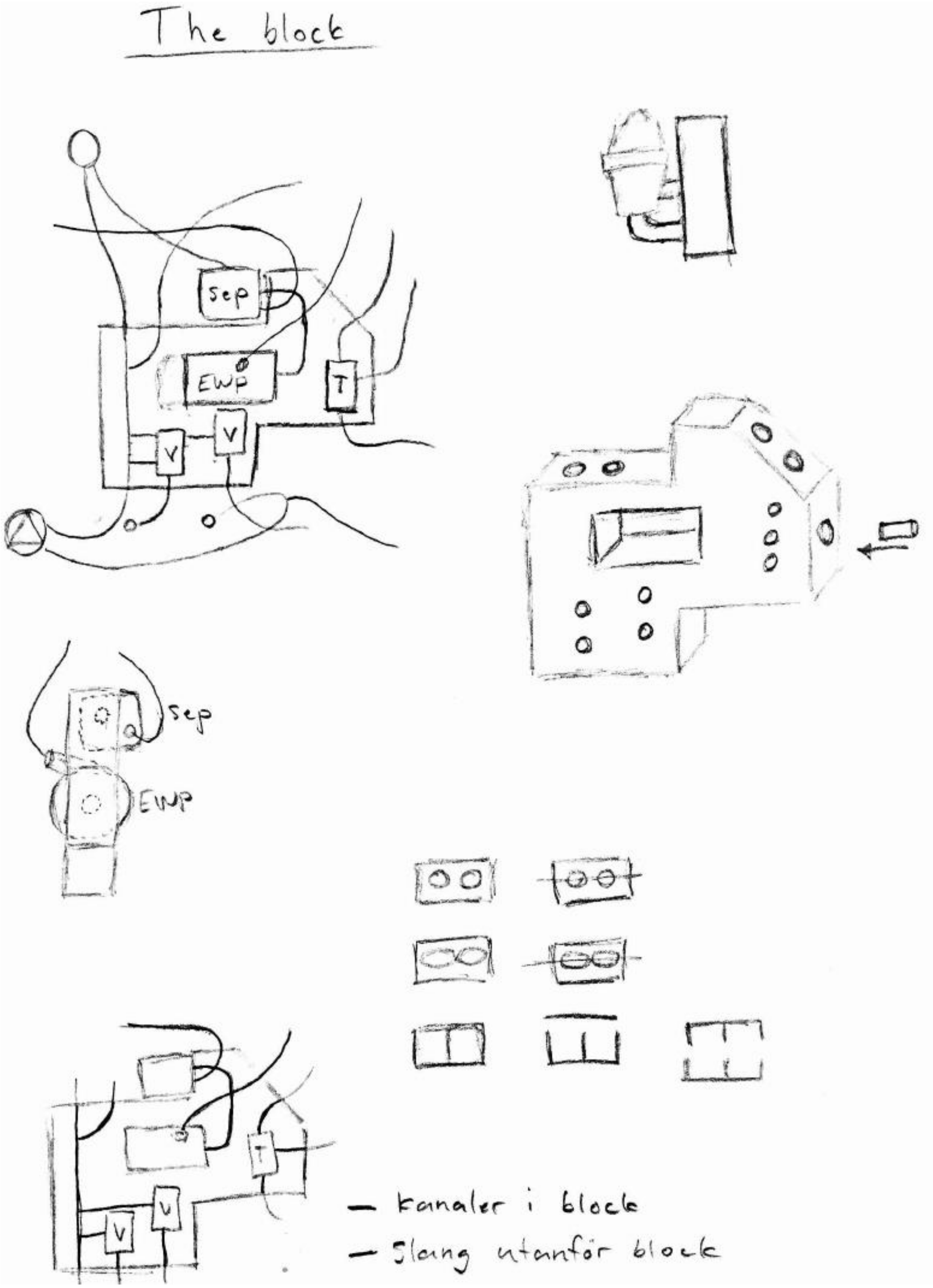
	AL	*TA*	*SSU*	*MV*	*FS*	*PM*	*CE*	*TOT*
Rating	3	3	4	3	3	3	4	3,29

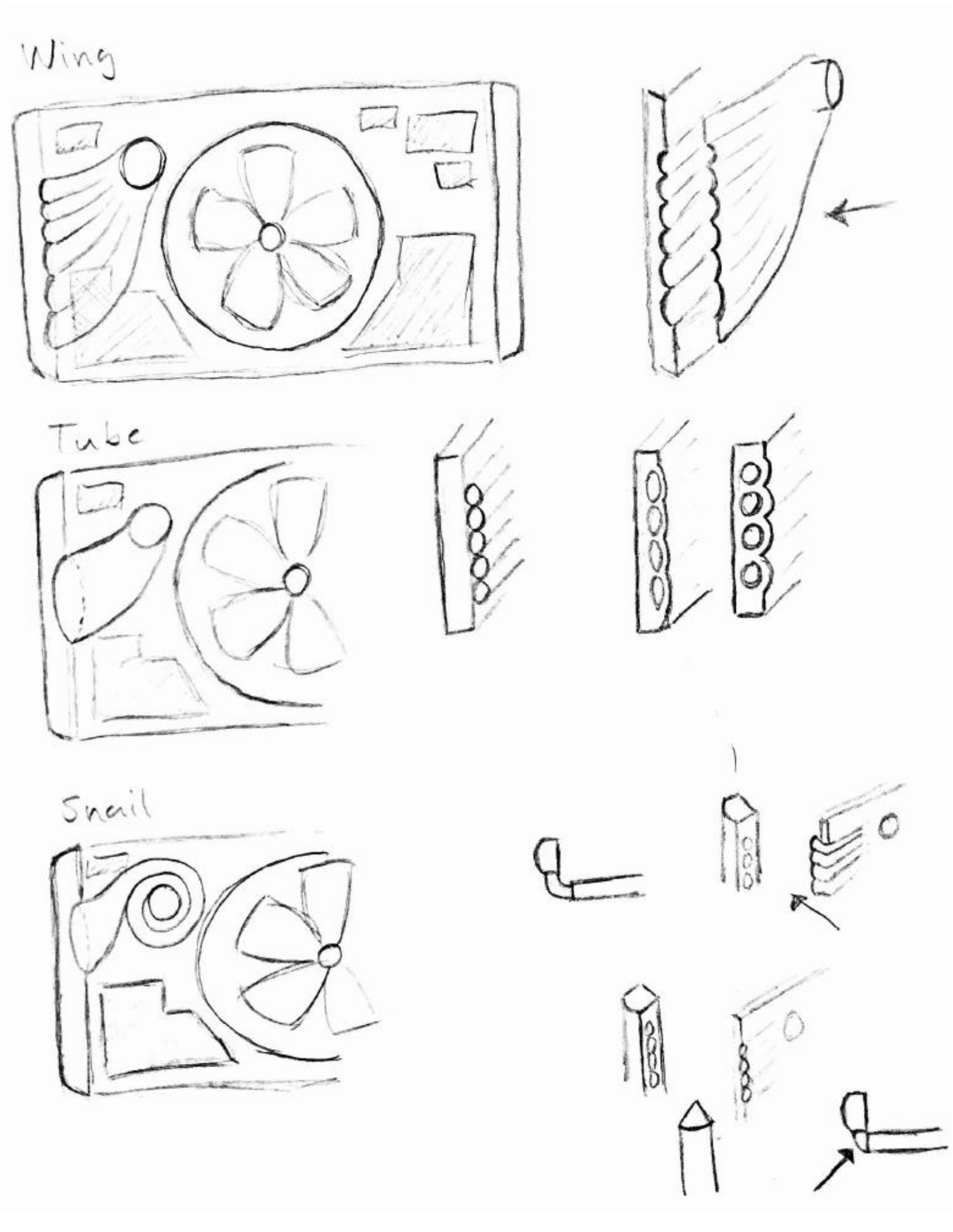
Summery

Idea name	*Rating (average)*
Cooling block	4,33
Change hose profile	3,67
Components/hose in fan shroud	3,5
Hose collectors	3,29
Cooling channels in components	3,21
Attach components on inlet/outlet	3,14
Air cooled components	2,42

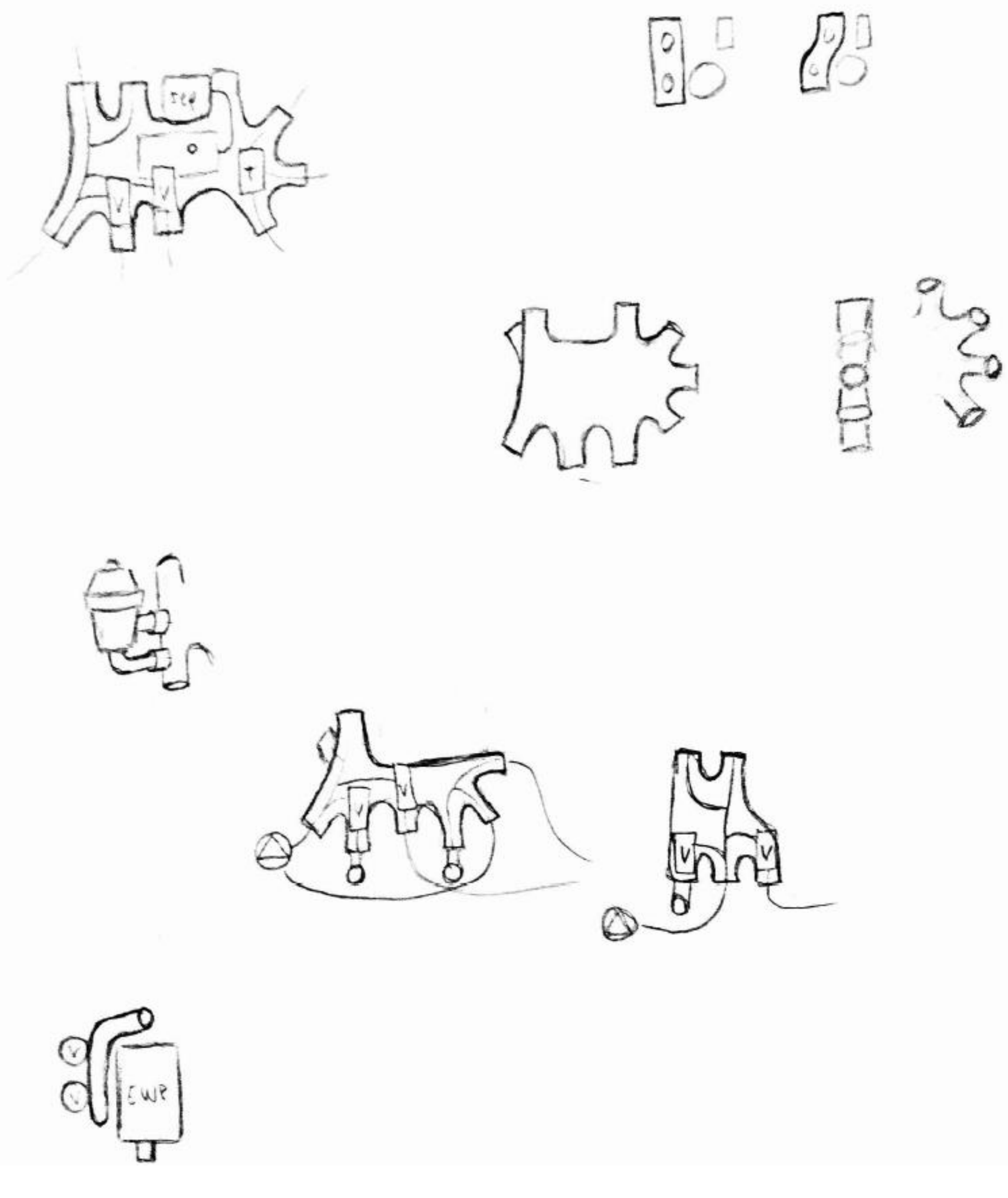
Appendix 12

More described concepts, the block, fan shroud and the fork.

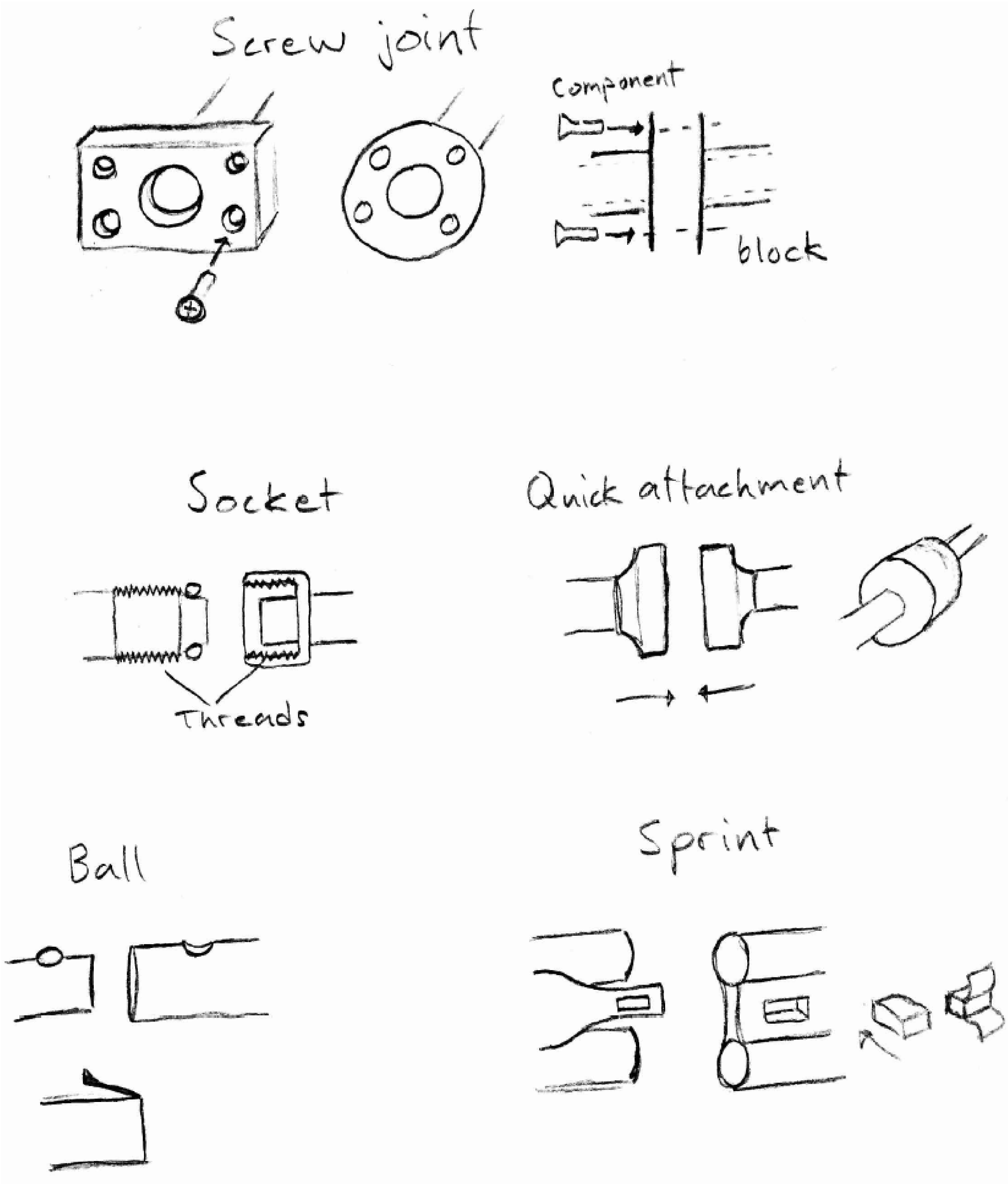


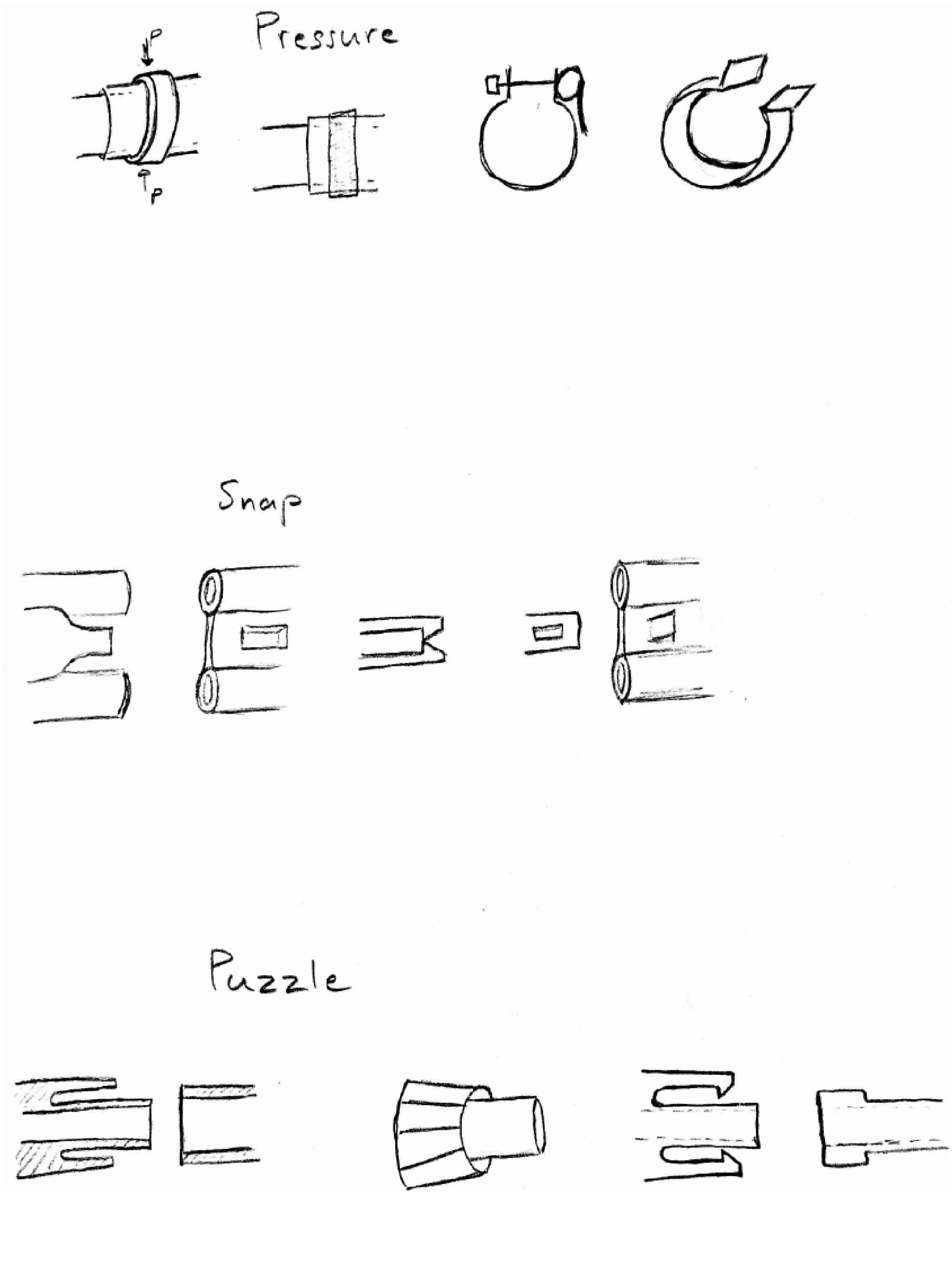

Wing
Tube
Snail

The Fork



Appendix 13
Ideas on different attachment strategies




Pressure
P
P
Snap
Puzzle

Appendix 14

Morphological matrix – The block and fan shroud

Morphological Matrix

Sub-function	Solution 1	Solution 2	Solution 3
Shape	Block	Fork	U-Block
Thickness	Simple	Fitted	
Channels	Circular	Square	Elliptic
Cut	Non	Upper part	Middle
Attachment	Integrate	Assemble same time	Assemble after
Material	Aluminum	Plastic	

Morphological Matrix

Sub-function	Solution 1	Solution 2	Solution 3
Water distribution	Wing	Tube	The snail
From shroud to tank	Fully integrated	Integrated shroud	Separate
Channels in shroud	Half channels with cover	Integrated	Separate

Appendix 15
Comparative figures between the current solution and concept solution

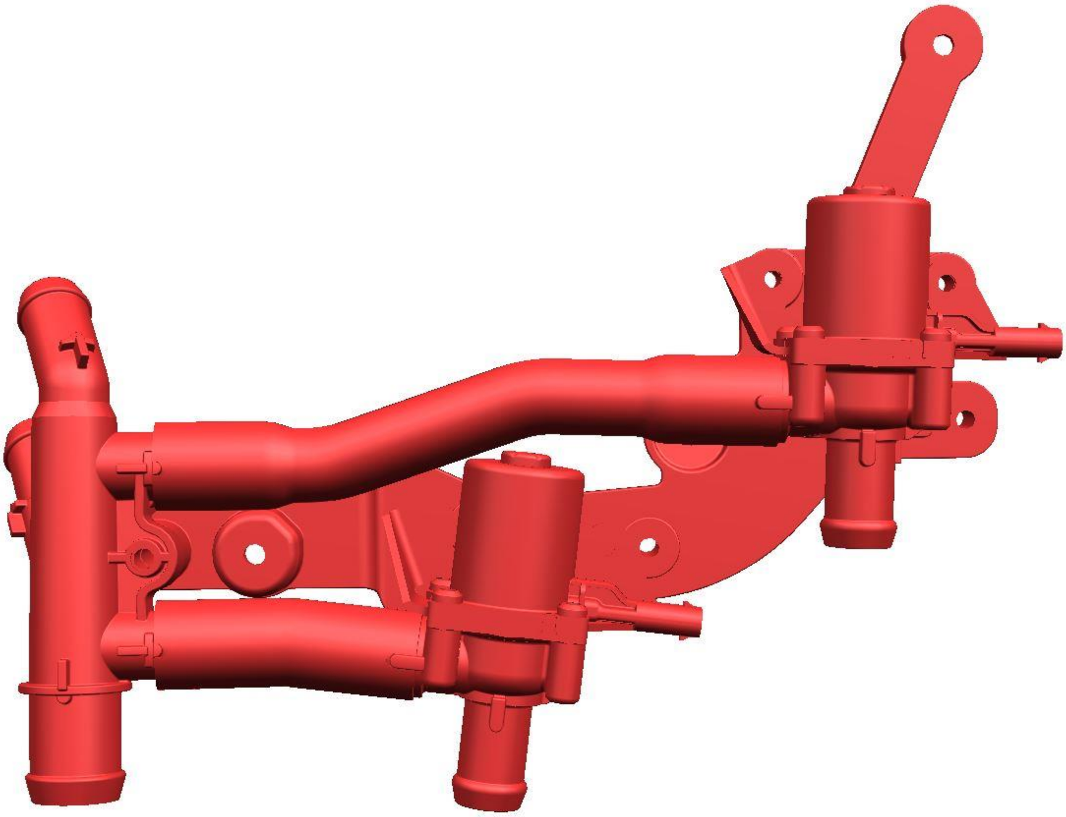


Figure 27. Current solution for VED

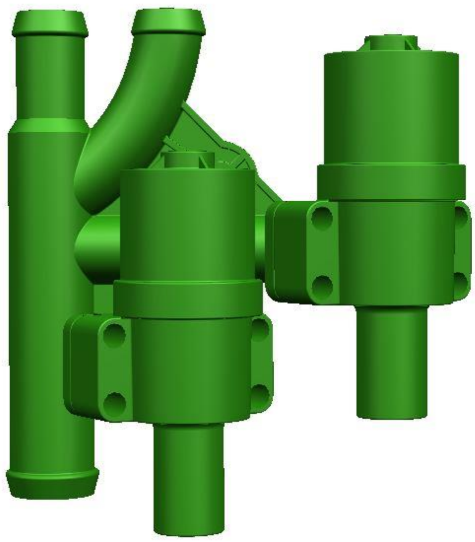


Figure 28. The Blork – Concept comparison with Figure 27

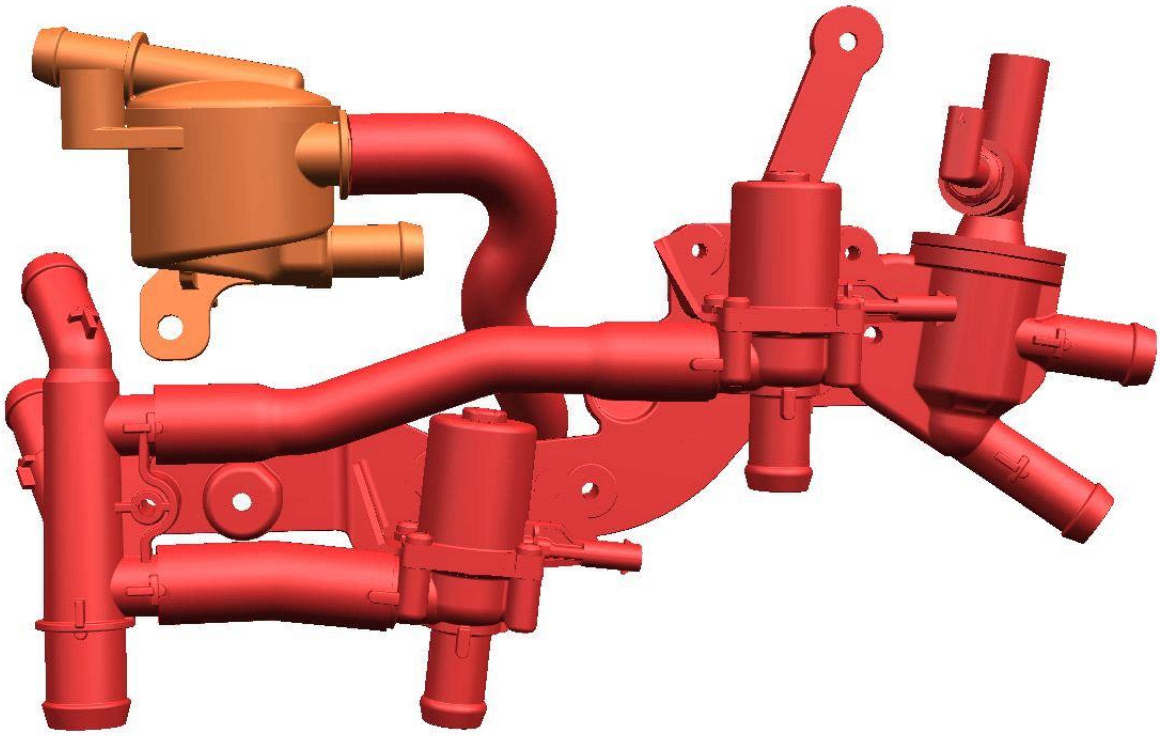


Figure 29. Current solution – The bracket

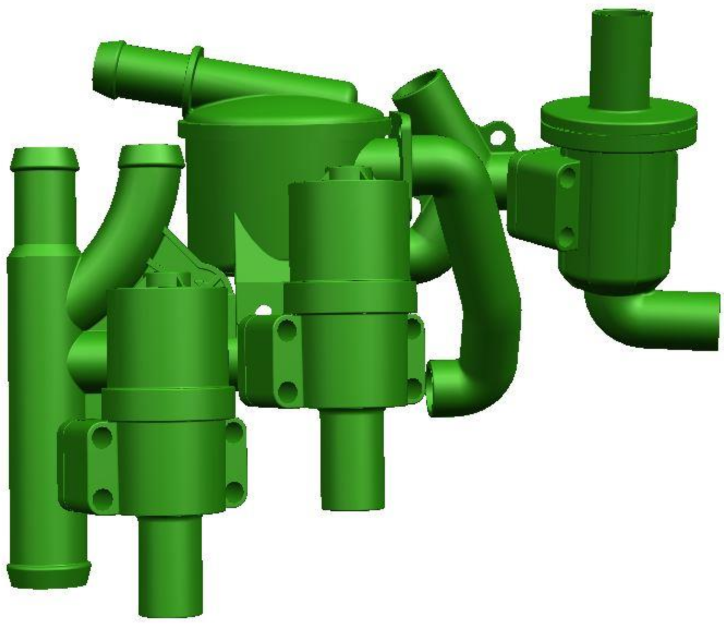


Figure 30. The large system

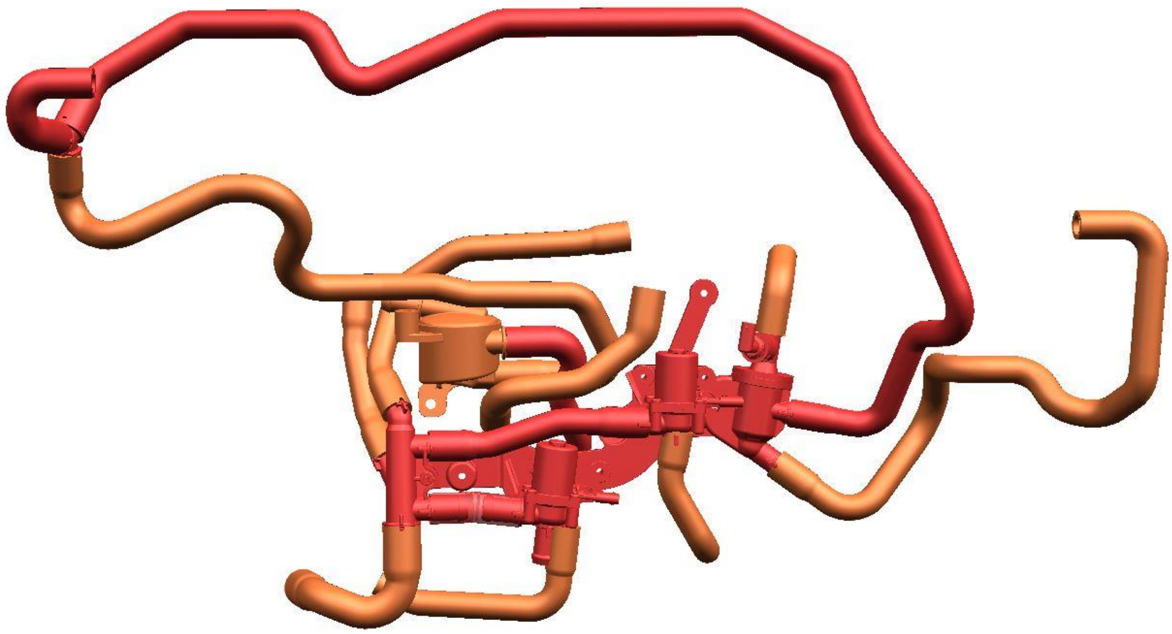


Figure 31. The current solution with hoses connected

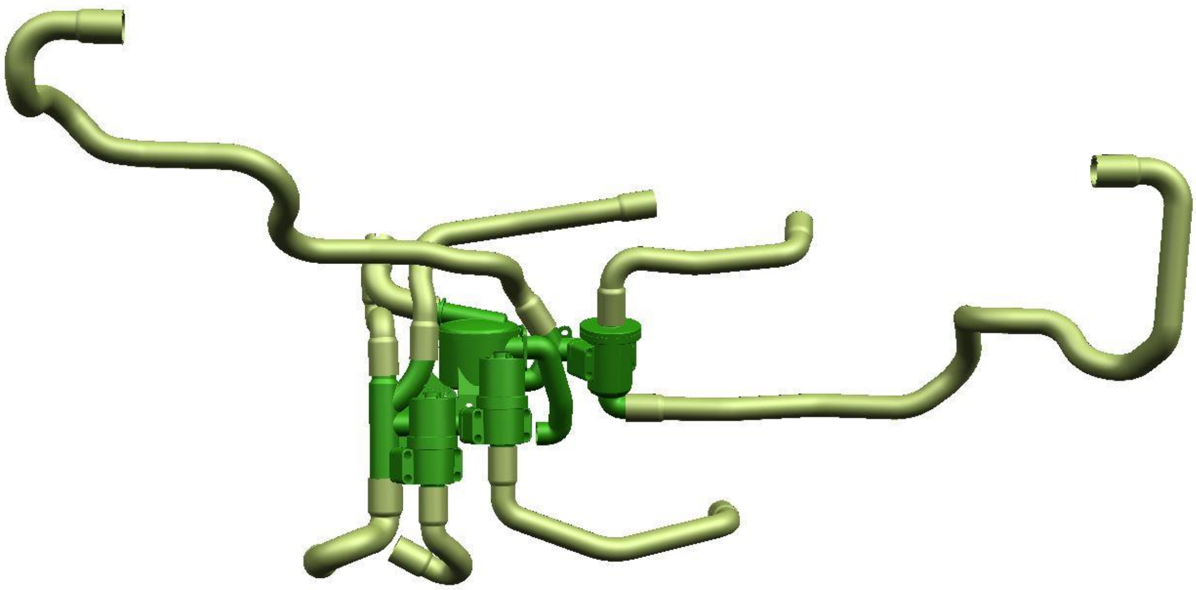


Figure 32. The large system with hoses

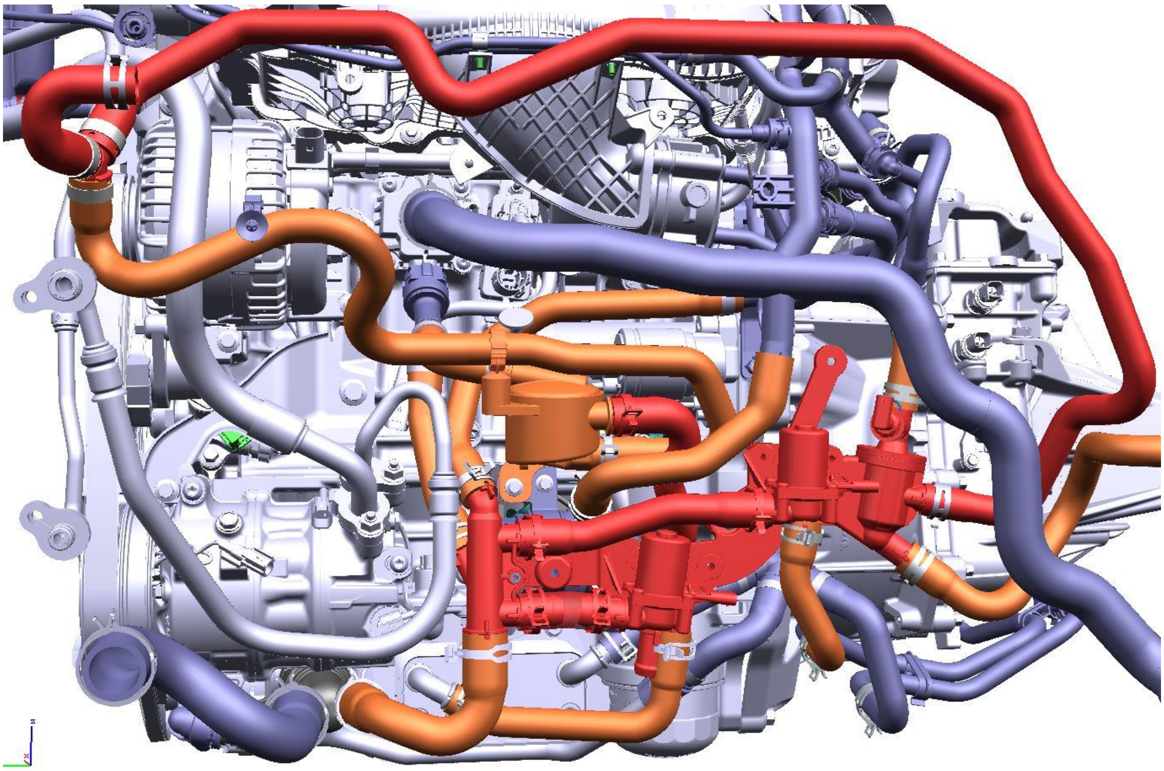


Figure 33. The current solution with the large bracket

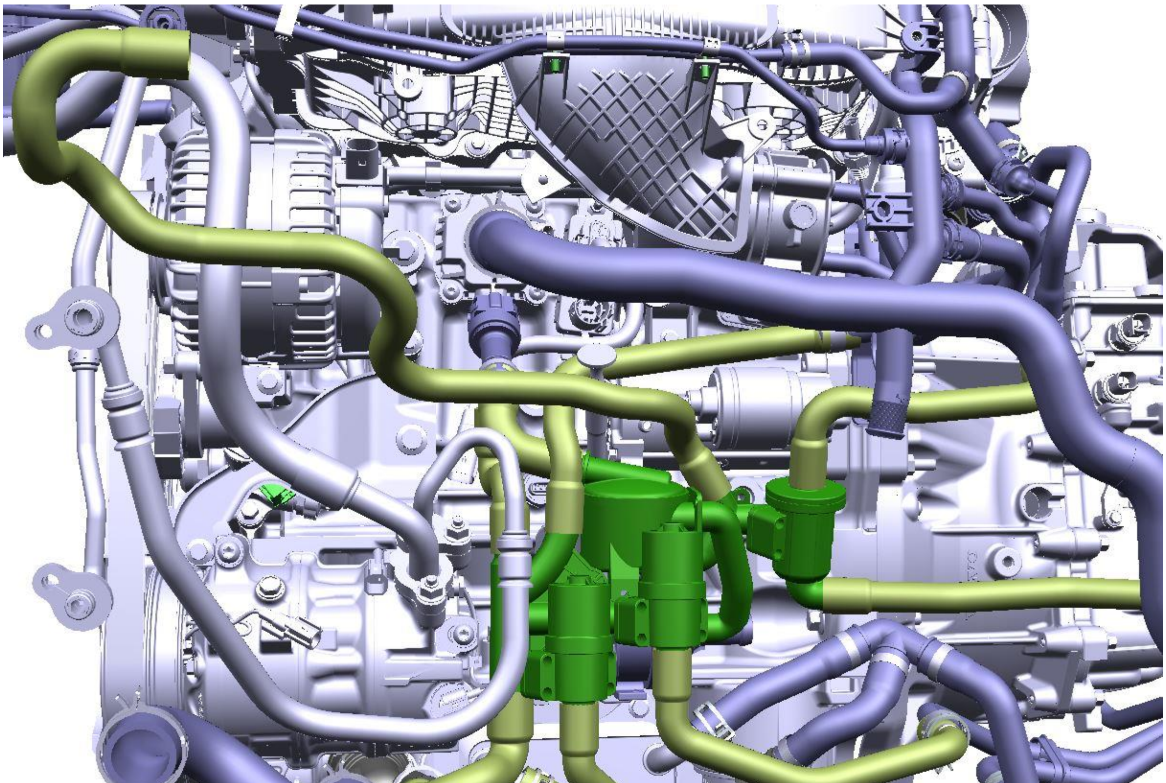


Figure 34. Zoomed for the large system with the modified concept