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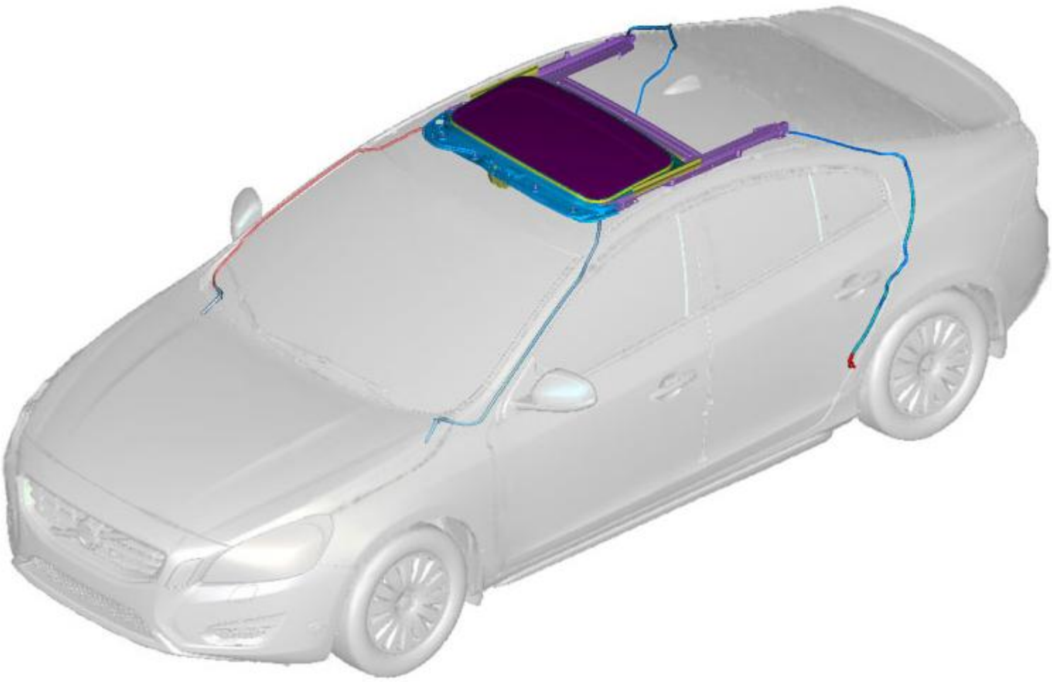

Development of new concept solution for sunroof drainage system

Solving a quality issue regarding an unwanted sound phenomenon in an automotive sunroof drainage system

MASTER OF SCIENCE THESIS IN PRODUCT DEVELOPMENT

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Cover:
Digital mock-up of a Volvo S60 with highlighted sunroof and its drainage system

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Abstract

This report is the result of a master's thesis project carried out at Volvo Car Corporations´ R&D department (Volvo Car Corporation is a Swedish car manufacturer) during the first half of 2011. The project concerned the investigation of an unwanted sound phenomenon occurring in the drainage system connected to the sunroof on the Volvo S60 and V60. The sound phenomenon had been identified as a quality problem, negatively affecting the perceived quality impression for VCC´s customers.

The Six Sigma strategy is implemented as a business approach at VCC and their improvement projects often follow the DMAIC methodology (Define, Measure, Analyse, Improve and Control). With this in mind this master's thesis project has also followed the DMAIC structure and several of the tools available within Six Sigma have been utilised.

The drainage system for the sunroof consists of a frame, within the main construction, with channels surrounding the entire sunroof panel which collects water. Each of the four corners of this frame has a drain hose attached, leading the water down through the structure of the car. At the end of the drain hose a drain plug is attached. This has two purposes; to provide an interface through the metal car body and to block any potential noise from entering the car interior. As mentioned, an unwanted sound phenomenon had been identified within the drainage system. For this phenomenon to occur a set of prerequisites had to be fulfilled. First of all, there had to be stagnant water in any of the two front drain hoses. The second and third prerequisite has to do with driving conditions. The car needs to travel at a speed around 100 km/h and either the sunroof and/or one of the side windows needs to be opened. These three prerequisites led to an overpressure in the bottom of the drain hose and an underpressure at the top of it. This in turn, had the effect that the water started to wander upwards inside of the hose, resulting in a "gurgling" sound phenomenon.

To solve this problem a set of concepts to remove the stagnating water or the pressure difference in the drain hose were developed. These concepts were screened, scored and ranked in three different development loops, leaving only two concepts left for verification. The two concepts both built upon the idea of introducing a non-return valve at the end of the drain plug. The final solution proposal involved a drain plug with a soft non-return valve consisting of a lid facing upwards that closed the end of the drain plug. The lid stopped the airflow originating from the pressure difference within the hose and eliminated the unwanted sound phenomenon.

To avoid the same problem in future car projects a few guidelines have been defined. The most important of these points out the necessity of having proper inclination on the drain hoses within the car. A certain inclination is recommended in VCC´s own design guidelines but the importance of actually making sure it is being followed needs to be stressed further.

Keywords: drainage system, sunroof, Six Sigma, DMAIC, sound phenomenon, improvement project, concept development, automotive, Volvo Car Corporation.

Acknowledgement

In this study new concepts for the drain plug connected to the sunroof system in the Volvo cars S60 and V60 were evaluated. The investigation was carried out for Volvo Car Corporation in Gothenburg, from January 2011 to June 2011 as a master's thesis for two master's students at Chalmers University of Technology. The Master's thesis is within the master's programme Product Development within the department of Product and Production Development at Chalmers University of Technology.

The investigation and different tests have mainly been performed at Volvo Car Corporation in Torslanda but also at Chalmers University of Technology. We would like to thank the many persons at Volvo Cars who helped us along the course of the project: Stefan Andersson, Anders Aronsson, Ulf Axevi, Linda Dahlqvist, Christer Dominique, Joakim Dryselius, Erik Gustafsson, Stefan Grösfjeld, Magnus Gullman, Heléne Hansson, Witold Hansson, Tommy Johansson, Anders Magnusson, Jimmy Norberg, Göran Nyman, Daniel Olsson, Peter Porsgaard, Harun Redzic, Niclas Sargren, Per-Anders Smedlund, Peder Söderström, Torbjörn Virdung and Leo Zuckerman.

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Gothenburg in May 2011

Annie Mortensen
Simon Niemelä

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Terminology and acronyms

A pillar	The roof supporting beams in the car, which goes from the engine compartment and front wheel house to the roof. It also separates the windscreen and the front seat side windows.
B pillar	The roof supporting beams in the car, which is placed between the front and back seat.
C pillar	The roof supporting beams in the car, which is positioned behind the passenger seat.
CAD	Computer Aided Design
CATIA V5	CAD software used at VCC, provided by Dassault Systèmes
CFD	Computational Fluid Dynamics
DFSS	Design for Six Sigma. A methodology widely used within the Six Sigma business strategy.
DMAIC	Design, Measure, Analyse, Improve and Control. A methodology widely used within the Six Sigma business strategy.
DMU	Digital Mock-up
FFF	Free-Form Fabrication
FMEA	Failure Mode and Effects Analysis. A tool used for identification of errors, their likelihood of occurring and the possible consequences they can lead to.
GSG	Solidity. A group at Volvo Cars which works with squeaks and rattle within cars.
MSA	Measurement System Analysis
NVH	Noise, Vibration and Harshness. An area of knowledge within automotive engineering and also a department at Volvo Cars which works with these problem areas.
PLM	Product Lifecycle Management
R&D	Research and Development
TR	Technical Regulation. A document stating design guidelines and requirements, used at VCC
TT-track	Test track located at Volvo Car Corporation´s production facilities in Gothenburg
VCC	Volvo Car Corporation

1. Introduction

This chapter gives an introduction and background to the purpose and expected outcome of the master's thesis project conducted at Volvo Car Corporation (VCC), Gothenburg. The problem that was to be solved and why this was of importance for VCC is also described.

Volvo Car Corporation has been around since 1927 when it was founded in Gothenburg by the engineer Gustaf Larson and economist Assar Gabrielsson. During the years the primary ownership has shifted along a few larger companies and in 2010 Ford Motor Company sold Volvo Cars to the Chinese car manufacturer Zhejiang Geely Holding Group Co. Ltd. Volvo Cars core values, with primary focus on safety and Scandinavian design, has always been the same though.

Today, Volvo Car Corporation is an international company with factories or other branches in Sweden, Belgium, Spain, China, Malaysia, Thailand and USA. The headquarters is located in Gothenburg, Sweden. The Volvo brand has developed to be one of the most recognised car brands in the world, with sales in over a hundred countries. (Volvo Car Corporation, 2010)

1.1 Background

In 2010 Volvo Cars introduced two new car models, the S60 and the V60, both models to be sold worldwide. Approximately 40 % of these cars are expected to be fitted with sunroofs. The purpose of these sunroofs is to provide lighting and a feel of "roominess" within the car, in other words to make the inside of the car feel bigger and brighter. Another feature is the possibility to vent the interior of the car in order to give a fresh sense of being outside, instead of inside a car.

The sunroof construction has a drainage system in order to ensure that no water enters the interior of the car. The water should not be allowed to be kept standing in the system as this can create unwanted sounds and leakage into the car interior. One of the main parts of the drainage system is four small hoses which are connected in the corners of the sunroof frame. The function of these hoses is to lead the water, which has found its way past the sunroof, out of the car. On the car models mentioned an unwanted sound phenomenon emerges during a certain driving condition. The sound phenomenon, which sounds almost like a coffee maker starts when the sunroof is tilted and the car is moving within a certain speed interval, and alternatively when the side window is open in combination with the speed interval. The sound is perceived as annoying for the persons riding in the car and cannot be eliminated by Volvo´s customers themselves.

A quick-fix solution has been implemented in production today but there is a need for a long-term solution. A study of why the sound phenomenon occurs and recommendations for how this phenomenon can be avoided in future car models is also important.

1.2 Purpose

The purpose of this project is to improve the quality impression of the Volvo car models S60 and V60, by eliminating the unwanted sound phenomenon associated with the sunroof drainage system.

1.3 Project goals and objectives

The objectives of the master's thesis project are to investigate the cause of the problem and how the products, in this case the entire drainage system, can be improved to eliminate the unwanted sound phenomenon. The focus lies on the drain plugs and hoses that are parts of the drainage system.

The goals and expected outcome of the project have been divided into a primary and a secondary goal. The primary goal is to develop new concepts for the drainage system or parts of it and present these as CAD models, the definite number of concepts is not specified. The secondary goal is to make physical prototypes of the most promising concept, in order for them to be tested on an actual car.

The primary and secondary goals are subject of available time and resources and hence, both goals are planned for but the time plan is subject to change.

1.4 Delimitations

The drainage system consists of canals, hoses and plugs. The whole system is not to be changed since it affects several other major parts of the car. Instead, the main focus lies on the drain plug, a short bent tube of rubber material placed at the lower end of the drain hoses and the drain hose, the hose leading the water from the sunroof to the drain plug. Since the problem with the sound phenomenon only occurs in the two drain hoses located in the front end of the car, the focus will only be on these two.

1.5 Outline of the report

The report is structured according to the DMAIC methodology and is divided into each of its different phases. To ease understanding of the report each chapter is introduced with a short text regarding what can be found in these.

1. INTRODUCTION: Gives an introduction to the problem at hand and introduces the reader to the contents of the report. The idea with the master's thesis project as well as this is important for Volvo Cars is stated.

2. PROJECT STRATEGY AND METHODS EMPLOYED: Describes the methodology as well as primary methods applied during the course of the project.

3. DEFINE – CREATING A BASIS FOR FURTHER WORK: Describes the drainage system, its different parts and how they work. The problem at hand is also described and the prerequisites needed for it to occur.

4. MEASUREMENT AND ANAYSIS OF DATA: This chapter consists of further investigations on the system and the unwanted sound phenomenon. Different experiments and tests are presented in this section together with the analysis of the result. To ease for the reader the Measure and Analysis phases of the DMAIC process have been placed in the same chapter. They are placed together as they are closely connected to each other and were carried out more or less in parallel.

5. IMPROVE – DEVELOPMENT OF NEW CONCEPTS: From the data acquired during the measure and analysis phases the process of new concept generation and selection is presented and described in this section.

6. CONTROL – VERIFICATION OF NEW CONCEPTS: Evaluation of the new improved concepts. Verification methods and their outcome are presented as well as what further verification that needs to be carried out.

7. DISCUSSION: A discussion on what could be considered in future projects and how the DMAIC methodology has worked for this type of project is found in this chapter. Recommendations for future work with the new concept are also stated.

2. Project strategy and methods employed

This chapter explains why the major methodologies used when carrying out this master's thesis project were chosen. The methods and methodologies will also be described to give a brief overview of how they work.

2.1 Six Sigma and the DMAIC methodology

The research and development department at Volvo Car Corporation works according to the Six Sigma business management strategy and uses the DMAIC methodology both for evaluating existing problems and within new projects. To enhance the connection to the industry and further widen the students' knowledge within the field of product development, the DMAIC methodology was used for investigating and developing the new concepts.

DMAIC stands for Define, Measure, Analyse, Improve and Control and has many aspects that are similar to the Deming cycle which consists of Plan, Do, Check and Act (Bergman & Klefsjö, 2010). DMAIC uses the five phases to characterise and solve the problem at hand. The first step focuses on defining the problem. The following two regards measuring the problem and the requirements on the product and then analysing the results to find the key inputs. When these have been found the improvement phase initiates and the development of a better product begins. When the improved product has been established the control phase begins and the new part is validated. (Six Sigma Academy, 2002)

In most new product development projects the knowledge about the product is very low in the initial steps of the process at the same time as many important and limiting decisions most often needs to be taken during this time. The design freedom is then limited by decisions taken early on (Almefelt, Introduction to Design Methodology, 2009). In this project, the cars in which the product shall be fitted is already in production, which limits the design freedom to a large extent since there is more or less no possibility for changes on the surrounding parts.

2.2 Methods employed

The methods that can be used for problem solving and product development are many. It can therefore be hard to determine which ones to use. The reason for the choice of methods is connected to the knowledge the authors of this report have gained through studies at the master´s programme Product Development given at Chalmers University of Technology. The methods are widely used by product developers and there are a lot of literature describing their strengths and usefulness. This chapter describes some of the main methods applied during this project and gives a brief theory part about each one.

2.2.1 Functional analysis

When a system or sub-system needs to be analysed with regard to its built in functionality and how it is realised, the use of functional analysis is a good approach. This type of analysis can be conducted in different ways depending on how much information there is available about the system in advance. If very little is known the simplest form of functional analysis can be implemented in the form of a simple process model; the black box. This model illustrates the system as a ”black box”, where the inputs and outputs of the system are known and displayed, see Figure 2.1. The purpose is to illustrate the function of a system, but what actually happens within the system to fulfil the purpose is however left out. Process models can be a lot more detailed than this, by separating the different sub functions and adding more and more detail, complex systems with several inputs and outputs can be modelled. . (Ulrich & Eppinger, 2008)

Figure 2.1- Illustration of the system as a "black box"

Other models are available which display the hierarchy of functions within the system and its sub-systems. These types of models can be a good option if it is hard to identify flows or transformations of operands. The different functions are typically expressed as a two word combination of a *verb* and a *noun.* (Almefelt, Design Methodology, Functional Analysis, 2009)

An example of a hierarchical function model is the function-means-tree, see Figure 2.2. At the top of the model the main function of the system or sub-system is described. The solution is then explained with a mean which is then decomposed into functions that help to realise the main function of the system. The next level breaks up the functions even further and this procedure is repeated until satisfactory detail level is obtained. The functions should express what the system does, without stating the solutions to the physical realisation. (Almefelt, Design Methodology, Functional Analysis, 2009)

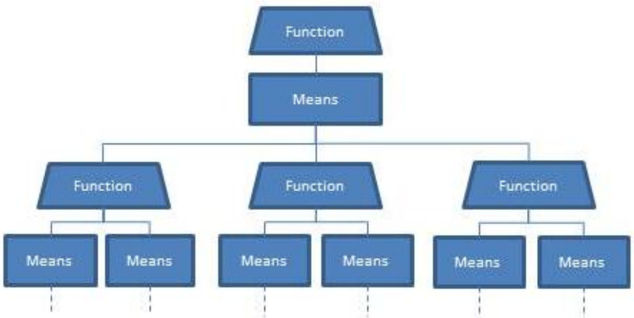


Figure 2.2 - Example of function-means-tree

2.2.2 Affinity diagram

Affinity diagrams can be used as a way of gathering and grouping ideas regarding a given topic. The affinity diagram is created within a group of people which is involved or affected by the project or issue at hand. The diagram can be used to find requirements as well as finding causes to problems and new solutions.

The method consists of four steps:

1. State the problem/issue that needs to be addressed. The problem/issue is phrased as a full sentence.
2. When the phrase is good enough the involved group start brainstorming regarding different ideas and issues for the topic. The ideas and issues are stated on, for instance, post-it notes and contain at least a noun and a verb.
3. When no more ideas are stated the post-it notes is sorted and moved into related groups.

4. As a final step a header or summary card should be created for each of the composed groups. (Brassard, Finn, Ginn, & Ritter, 2002)

2.2.3 Kano model

The different needs and requirements from customers are many and are mainly divided into different properties when stated in a requirement specification. The Kano model focuses on how the customer perceives different requirements. The perceptions of the customers are divided into three main groups in the model; “must be”, “more is better” and “delighters”. To illustrate how the different needs affect the customers a model is used where the requirements can be stated, see Figure 2.3. “Must be” requirements are those which the customer most often never thinks about but must be there for them (e.g. a car should have an engine). Then there are the “More is better” needs, those which linearly affect the customers (e.g. low fuel consumption). Last but not least are the “delighters”, expectations that delight the customer and which he or she haven’t thought about before buying the car (e.g. new technical solutions). As technology advances more or less all of the needs that once where “delighters” will change category and become “more is” better and in the end “must be”.

The process of creating a Kano model consists of three main steps:

1. Gather requirements regarding the product
2. Sort the requirements into the three topics: Must be, more is better and delighters
3. If needed, gather additional requirements and place these beneath the right topic, according to the Kano model

(Brassard, Finn, Ginn, & Ritter, 2002)

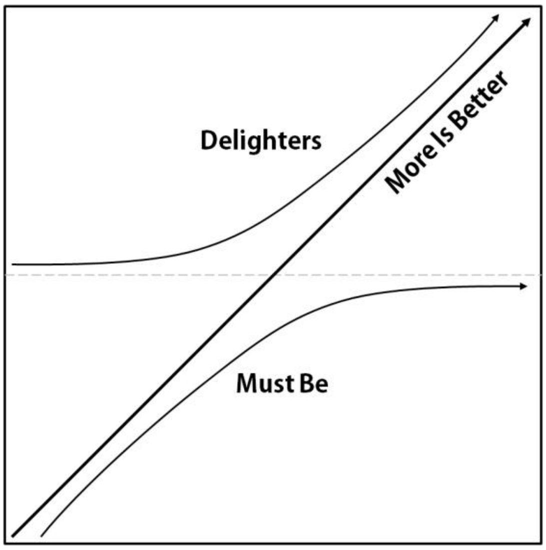


Figure 2.3 - Illustration of Kano model

2.2.4 Ishikawa diagram

The cause-and-effect diagram also known as an Ishikawa diagram or a fishbone diagram is a tool to help identify and visualise the potential causes of and their effect on a specific problem or event. It was first introduced by Kaoru Ishikawa during the 1960´s. As part of the seven management tools within the Total Quality Management and Six Sigma methodologies it is used in a wide array of companies in many different industries (Bergman & Klefsjö, 2010). Volvo Car Corporation uses the tool as part of their DMAIC methodology.

The method incorporates brainstorming to identify the different major causes of the problem that is being investigated. Because of this, it is appropriate to use a cross-functional team when creating the diagram. (Brassard, Finn, Ginn, & Ritter, 2002)

The main event or problem which is investigated is placed furthest to the right, acting as head of the fish skeleton. The major causes to the main event or problem are placed as branches to the fishbone skeleton, see Figure 2.4. These major causes are broken down further in the next step to identify the possible causes of each major cause. This process is repeated until no more information can be added to the diagram, due to lack of ideas or insufficient knowledge. The diagram takes the shape of a fish skeleton, hence the name fishbone diagram.

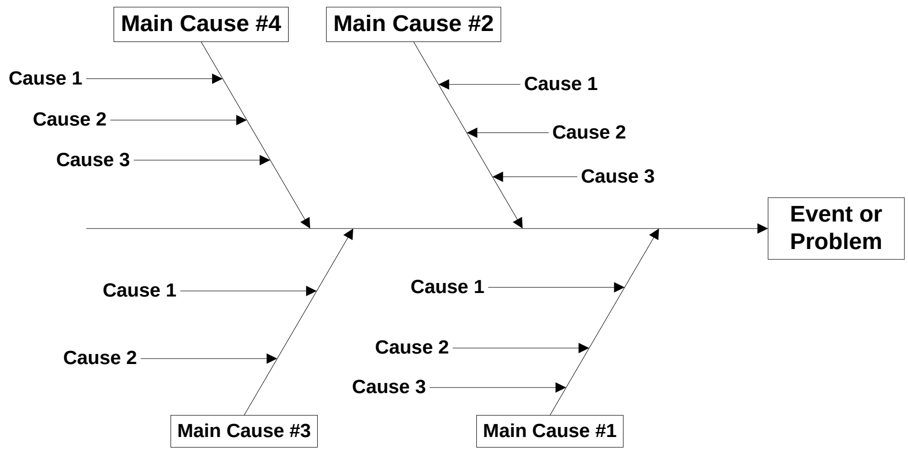


Figure 2.4 - Illustration of Ishikawa diagram

2.2.5 Failure mode and effects analysis (FMEA)

Failure Mode and Effects Analysis is a method for evaluating how a part or product can fail during its lifetime. The analysis evaluates what effects these failures can have and how they are generated.

FMEA is used during the measure step for evaluation of the problems with the existing drain hose and plug. An FMEA can also be used during the improvement phase of the DMAIC process for evaluation of the new solution proposals. The purpose is to evaluate potential failures within the new concepts as well as their potential severity and likelihood. When the failures are identified the concepts can be improved and measures to prevent failure are documented. (Brassard, Finn, Ginn, & Ritter, 2002)

2.2.6 Fault tree analysis (FTA)

Fault tree analysis is a good tool for illustration of how problems are related to different parameters and events. The tree uses logical signs to graphically illustrate the relations between parameters and the problem at hand.

When using the method a problem or risk is used as the top event, this event is followed by logical gates and then by preceding events. The top event is broken down until the basic causes have been identified as basic events. Statistical calculations of frequency or probabilities are one common area of use. (Shahriari, 2010)

2.2.7 Measurement system analysis (MSA)

Before conducting any measurements of a process it is important to make sure that the measurement method used works as intended, without contributing too much to the overall variation within the results. If the measurement system contributes to more variation than the process itself it might be very difficult to draw any conclusions from the measurements. An MSA needs to be carried out in order to make an assessment of how reliable the measurements are, as well as how robust with respect to variation the method is (Six Sigma Academy, 2002). If the measurement system itself contributes to a lot of the variation there is a large risk of making judgments on false grounds. The data collected will then be misleading and decisions might not be based on facts.

Mathematically the MSA can be described to as a quantification of the different parts of variation as Equation 2.1 and Equation 2.2 illustrates. The σ denotes the standard deviation.

$$\boldsymbol{\sigma_T^2 = \sigma_p^2 + \sigma_m^2} \qquad \textit{Equation } 2.1$$

$$\textit{Total Variance} = \textit{Process Variance} + \textit{Measurement Variance} \qquad \textit{Equation } 2.2$$

It is also possible to differentiate between variability and accuracy of the measurement system. Reproducibility and repeatability address the variability of the measurement system, while bias, stability and linearity address the accuracy. The so called Gage R&R methodology (where R&R stands for Reproducibility and Repeatability) can be used for an initial assessment on the measurement systems´ contribution to the total variance. (Breyfogle III, 2003)

Reproducibility states how well the different measurements on the same thing taken by multiple operators match. Repeatability on the other hand states the ability of the measurement system to return the same value when one operator measures the same unit several times. (Six Sigma Academy, 2002)

Proper preparations need to be made before conducting the analysis, as with most experiments. Standardised forms exist for the gage R&R study, as well as statistical computer software that helps calculate the different proportions of process- and measurement variance.

2.2.8 Design of experiments (DoE)

The actual term, *Design of Experiments*, refers to the method of conducting experiments in a structured way. This is done in order to measure how much a certain set of parameters affect a given process or performance of some function, as well as how these parameters affect each other. By using a structured way of conducting experiments it is possible to maximise the information acquired for the effort made. The interactions of different parameters and their effect on the process can also be quantified. The quantification of effects can be used to find the parameters that have the greatest effect on the end result and hence, resources can be directed to improve or change the process. (Brassard, Finn, Ginn, & Ritter, 2002)

Experiments can be both time and resource consuming and any reduction in these aspects is of course valuable.

Another major benefit gained from conducting structured experiments is the above mentioned possibility to measure the effects of the interaction between two or more parameters. This is not possible to achieve by conducting experiments where one parameter at a time is changed, in order to measure its effect on the output. If one were to conduct such experiments, to find an optimum, by making a trade-off between two variables for instance, it would be quite likely that the results from the experiments would show another optimum than the real one. Interaction effects would also be lost.

The DoE can be designed in two ways, depending on how many factors that need to be examined and how much resources that can be put on examining them. If only a few factors influence the outcome of the experiment a full factorial experiment design is the best choice. In this type of experiment design all combinations of factor combinations are investigated respectively. A two level full factorial experiment design is shown in Table 2.1. Three factors, with a high and a low level, and their respective effect on the output can be measured in eight experiment runs, as well as their interaction effects can be measured. The high and low levels have to be decided in advance. (Breyfogle III, 2003)

In the table the different high and low levels are represented with "+" for high level and "–" for low level. To calculate different factors interaction AB, BC etcetera is used, and these levels are calculated through multiplying the plusses and minuses for the combination. Two plusses multiplied equals a plus, two minuses equal a plus, and a minus and plus equals a minus.

Table 2.1 - Full factorial experiment design, with interaction effects

	Factors and interactions							Experiment response (X)
Trial	**A**	**B**	**C**	**AB**	**BC**	**AC**	**ABC**	
1	+	+	+	+	+	+	+	X_1
2	+	-	+	-	-	+	-	X_2
3	+	+	-	+	-	-	-	X_3
4	+	-	-	-	+	-	+	X_4
5	-	+	+	-	+	-	-	X_5
6	-	-	+	+	-	-	+	X_6
7	-	+	-	-	-	+	+	X_7
8	-	-	-	+	+	+	-	X_8
Output (Y)	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	

The results of the experiments can be displayed in a square or a cube. This makes for a great visual tool to identify in which direction the parameters should be changed for greatest effect on results. The square works for two parameters and the cube for three. An example of the cube can be seen in Figure 2.5. The effects of the different scenarios, when each parameter is high or low respectively, in combination with the other parameters is plotted at the corners of the cube.

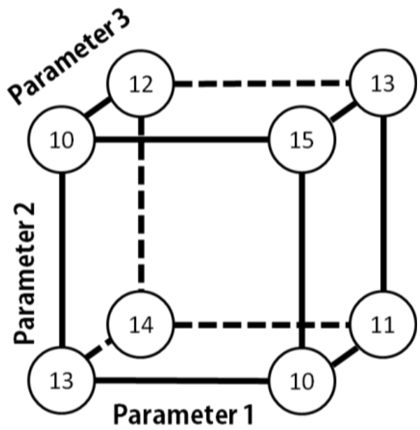


Figure 2.5 - A cube displaying the effects of three factors at two levels

With the help of this simple illustrative tool it is possible to see in which direction one should continue with the experiments for further investigation.

2.2.9 Morphological matrix

During the development of new concepts there exist tools that helps facilitate creativity and give structure to the development work. One useful tool that does just this is the morphological matrix. The matrix is used to combine concepts for different sub-functions to create alternative concepts for the whole product or system.

The matrix consists of a set of rows and columns, representing sub-functions and concepts for solving these respectively. Pictures are commonly incorporated to describe the different concepts at every sub-level along with a few rows of text. The morphological matrix can be used to create an array of different concept proposals for the final solution. The final solution uses combinations of the different part solutions and the number of possible solutions is very large. By using this kind of matrix, documentation of solution proposals is automatically generated and structured. (Weber & Condoor, 1998)

2.2.10 Elimination matrix

After a set of concept proposals have been generated it is important to narrow down the number of concepts to continue the development work. An effective and easy to use tool to help the execution of this task is the so called Elimination matrix.

By listing the different concepts proposals along the rows in the matrix and assessing their fulfilment of a number of criteria along the columns, it is possible to eliminate solutions that do not perform as needed. Examples of criterions that can be assessed; solves main problem, fulfils all demands, is compatible/realisable, is safe, fits product portfolio and is enough information available. The use of this rather simple tool quickly removes concepts that are not good enough. (Almefelt, Design Methodology: Evaluation and Decision-making, 2009)

2.2.11 Pugh concept screening

When a set of concepts have to be compared against each other in order to make a decision on which ones that should advance in the development process, the Pugh screening matrix can be utilised. In this matrix the different concept proposals are compared against each other and ranked according to how well they fulfil a given set of requirements or needs. The latter should be identified as requirements/needs that are important to not just fulfil but also to maximise/minimise.

The Pugh matrix identifies weak concepts rather than eliminating any solutions. It can be used to identify areas of improvement on the existing concepts and the process can be iterated in order to create a set of concepts that are as good as they can be before advancing to the next step in the development process. (Almefelt, Design Methodology: Evaluation and Decision-making, 2009)

The Pugh matrix works by choosing a datum concept and comparing all the other concepts with this datum for every requirement or need that is being looked into. A "+"," –" or "0" is written on the corresponding position in the matrix if a concept is better, worse or equal to the datum concept respectively. The net score is calculated by adding all the "better than" signs in the column for each concept and subtracting the number of "worse than" signs. When all concepts have been compared to the datum a new datum is chosen among the concept proposals. The process is then iterated until a converging ranking amongst the different concepts is acquired. This can also be performed with weighted criterions. (Ulrich & Eppinger, 2008)

When the process is over, it is possible to either continue to develop all the concepts or more likely, remove the ones with the lowest score in order to free resources that can be used to develop the more promising concepts.

2.2.12 Kesselring concept scoring

In order to rank the remaining concepts it is possible to use another kind of matrix, the Kesselring concept scoring matrix. It is, as the name indicates, a method used for scoring the different concepts in order to offer a more refined comparison of solution proposals as compared to the Pugh matrix. The scoring offers the possibility to choose the best concepts for further development.

The criteria used for ranking could be the same as in the Pugh screening matrix, however it is possible to further break down the criteria to offer more detail when conducting the assessment. The weights connected to each criterion can be calculated by using pair wise comparison in a different matrix, all criteria are then evaluated against one another to determine which that are most important. The scoring scale can differ according to the needs of the development team, a good example is to use 100 percentage points to divide between the criteria or by simply giving the criteria a score from 1 to 5. The more resolution added to the weightings the more time consuming the process of scoring the concepts will be. (Ulrich & Eppinger, 2008)

When all criterion have been weighted and the corresponding scores have been added to the matrix for each criteria and concept it is possible to calculate the total score for each concept. This is done by multiplying each weight by each score for every criteria and concept. The scores gained from this are then summed up and a ranking of concepts can be carried out.

Similar to when using the Pugh screening matrix it is possible to improve and alter concepts during the scoring process. The scoring is then repeated for the modified concepts and new rankings can be conducted. (Ulrich & Eppinger, 2008)

2.2.13 Rapid prototyping

During the development of new concepts for the drain plug it will be important to create prototypes for tests and verification. The technology, or rather collection of technologies, most suitable for creating functional prototypes in this project is called Rapid prototyping, or free-form fabrication as it is sometimes referred to as. Several competing technologies for Rapid prototyping exist and they all utilise CAD models for fabrication of physical prototypes. They can be seen as 3D-printing technologies and are a fast way of creating both visual as well as functional prototypes. The technology works by adding one cross-sectional layer at a time and for instance using a laser to solidify a liquid or powder (depending on which material that is used). The prototypes are most often created in plastic materials but the different technologies offer the possibility to create prototypes in other materials as well, including metals and ceramics.

By using Rapid prototyping it is possible to create 3D prototypes a lot earlier during the development process than what is normally possible and also at a lower cost. Used in the right way it can reduce development time and improve overall quality in the final product. (Ulrich & Eppinger, 2008)

3. Define - Creating a basis for further work

Define is the first step in the DMAIC methodology. During this phase the problem is identified and defined. To enable and ease future work a good description of the problem is important. The chapter will explain the current solution, identify the problem, describe the short term solution that has been implemented at this time and last but not least gather the initial requirements.

In order to be able to define a system and its problem areas a deep knowledge of the system and its surrounding parts is of importance. To get this knowledge regarding the sunroof drainage system on the Volvo S60 and V60 a deep study was needed. The knowledge was gained through the study of the separate parts, physical products, CAD models and in Digital Mock-ups.

The system has also been studied as a whole during assembly in a V60 at VCC´s production plant in Gothenburg. To understand the problem test driving was performed and existing documentation regarding the sound phenomenon was studied. The reason why the S60 and V60 have the exactly the same drainage system in the front has to do with their shared platform and that they are identical in front of the B pillar. The S60 is manufactured in Gent, Belgium while the Volvo V60 is manufactured in Volvo Cars assembly plant in Gothenburg, Sweden.

3.1 Description of the current solution

In order to better understand the different functions built into the sunroof drainage system and how these are realised in the product, a function-means-tree was created. By using this tool for functional analysis it is also possible to get a better understanding of the role of the drain plug as part of the system. Two separate function-means-trees were created, one for the complete drainage system and one including only the drain plug itself. The result is displayed in 0.

The drainage system is an important part of the sunroof system in the Volvo models S60 and V60. Without the drainage system, water can enter the interior of the car and negatively affect the quality impression. The entire sunroof system is displayed in Figure 3.1. Top down the drainage system begins in the frame of the sunroof. The trenches on each side of the sunroof collect water which passes the seal between the sunroof glass and car body. Each corner of the trenches is tilted downwards to an opening which is connected to a drain hose. The front drain hoses are then led towards their closest A pillar and down along it, hidden in the interior. The drain hose can be seen in Figure 3.2 which is a DMU of the drain hose in a car. When the drain hose reaches the height of the dashboard it is faced towards the centre of the car and is lead behind the dashboard and then connected to the drain plug. The passage path of the drain plug is through two sheets of metal, placed with space in between, which makes the design of the plug important to ensure that the plug passes through both holes without risk of poor assembly.

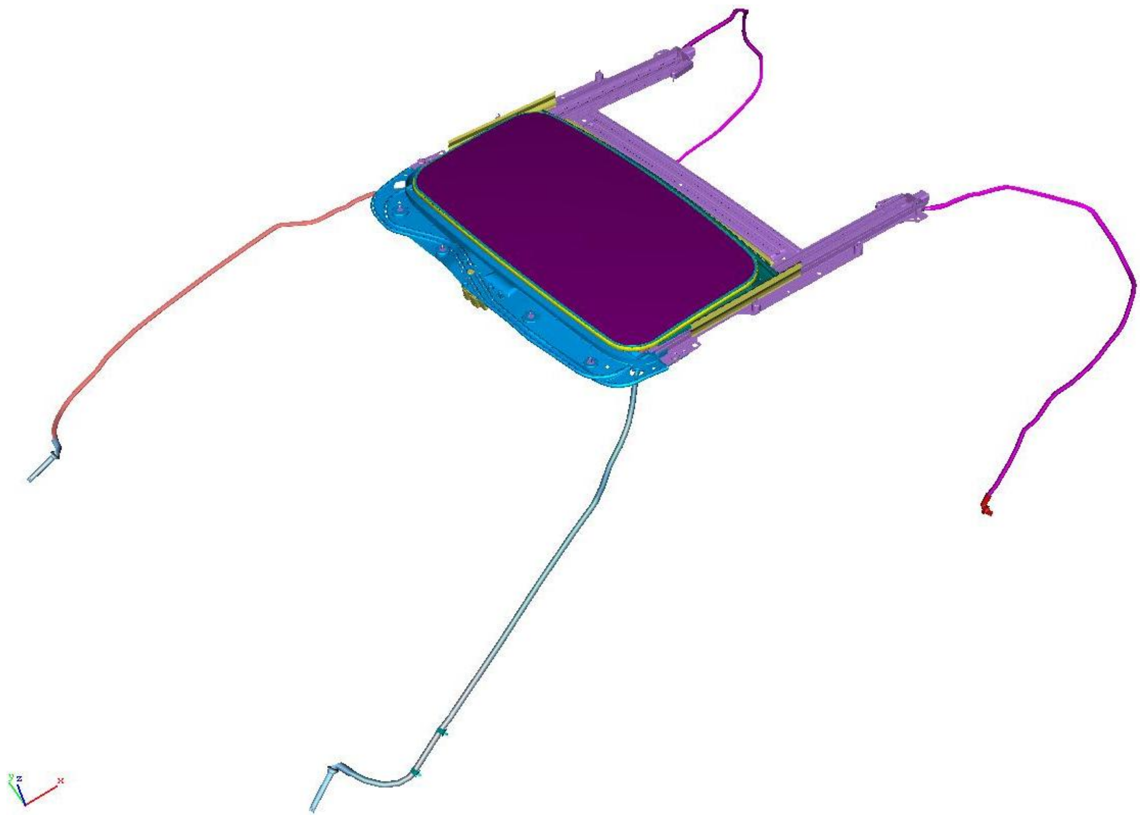


Figure 3.1 Digital mock-up of entire sunroof system for S60 and V60. Left is the front of the car.

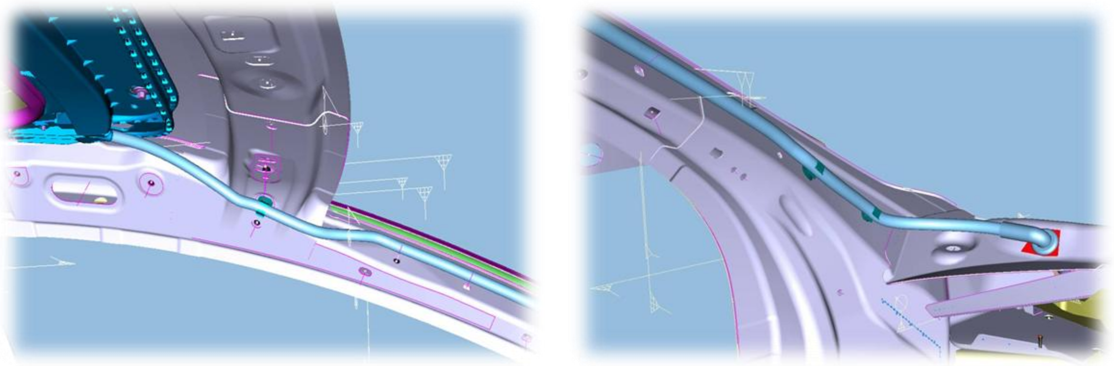


Figure 3.2 - DMU of the drainage hose in the car. Left - Drain hose connected to the sunroof. Right - Drain hose connected to the drain plug. The hose goes down along the A pillar of the car.

The swell on the drain plug is a sound plug that is facing the outlet hole to keep it tight and prevent engine compartment noise from entering the car interior. The outlet from the drain plug is through a cross-shaped opening. The drain plug used today is manufactured by Primo in Limmared Sweden through injection moulding, the drain plug is illustrated in Figure 3.3.

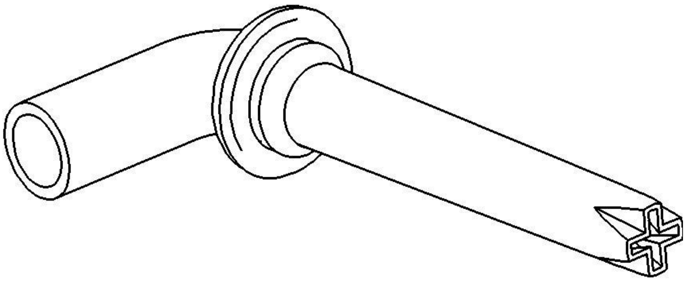


Figure 3.3 - Illustration of drain plug used in S60, V60 and XC60 today (Volvo Car Corporation, 2009)

The cross shape of the drain plug originates from an older solution in which the drain plug was more or less closed by the soft rubber, shaped as a cross which opened when water pushed on it, see

Figure 3.4. The cross shape was in order to close off the drain plug to eliminate sound from the engine compartment. However, there have been reports regarding flooding problems within these plugs since dirt has got stuck and closed the opening. Another problem has been in hot and moist climates where microorganisms have grown and clogged it. These events have led to the opening-up of the plug in order to minimise the risk of the problems.

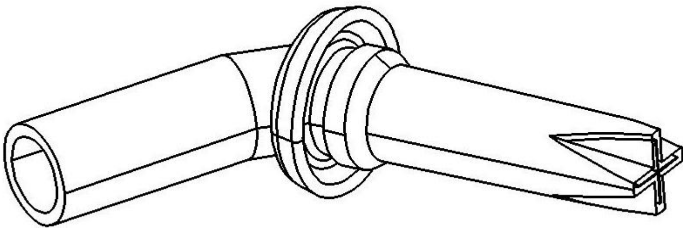


Figure 3.4 - Illustration of a more closed drain plug design (Volvo Car Corporation, 2008)

The purpose of the drain plug is to lead the water from the drain system out into the cold zone in the engine compartment, as well as damping the noise from the engine compartment and eliminate the risk of it entering the interior of the car. The cold zone is an area in the engine compartment which has been sealed off from the engine in order to minimise sound and also hot and smelly air from it. The Air-condition intake is also placed in the cold zone and this is the main reason for why this area is divided from the engine compartment.

When the water has passed the drain plug it enters the so called plenum tray inside of the cold zone. The purpose of the plenum tray is to seal off sound from the wheel arch, as well as forcing the water to exit in proper areas of the car. The plenum tray also collects water that is drained from the windshield in the front of the car. The outlet from the plenum tray is through a flap valve. This valve is kept closed when the tray is dry and opens when water presses on it, the water then exits behind the wheel arches of the front wheels.

Assembly of the drainage system is performed in steps. Initially the sunroof, which is a module of its own, is installed on the car and with it the trenches that collect water. When this has been done the drain hoses are first attached to the outlet hole connected to the drainage trench and then placed in different plastic clips down the A pillar. Finally the long end of the drain plug is passed though the outlet holes of the car body and then the drain hose is connected to its short end on top of the car body.

One of the main reasons why the drainage system differs between car models is due to differences in the surroundings. They decide where the drain hose and plug can be placed and where it is allowed to drain water. The placement of the drain plug is often chosen from the placement of the pre-made holes in the car body, originating from the manufacturing process. The drain hoses have in general stayed the same with regard to material and diameter, the drain plug on the other hand has gone through some changes over time. The general form has stayed the same but with changes in material stiffness, wall thickness and shape of the outlet hole.

The drain plug is subjected to a classical product development paradox. This is within contradicting needs for the fulfilment of the two main purposes of the drain plug. In this case the contradicting needs are: drainage properties versus sound isolating properties. These two are contradicting since the drainage properties would benefit from a large and open tube, while the noise isolation properties would be improved with the tube as small as possible and preferably closed.

3.2 Problem identification

The current drainage system connected to the sunroof has a built in flaw creating an unwanted sound phenomenon at a certain driving condition. The affected models are currently the S60 and V60, introduced on the market in 2010.

The phenomenon was first discovered during test drives with the V60, by engineers from the Solidity department, at Volvo´s test track in Torslanda. The sound phenomenon has only been identified during a certain driving condition.

The unwanted phenomenon appears as a gurgle, sounding almost like a coffee maker in operation. The sound is loud enough to create annoyance for the driver and passengers of the car and it is not possible to get rid of it without changing the specific driving condition (this should not be the solution). Hence, the sound has a negative effect on the quality impression of the car.

The prerequisites for the sound phenomenon to occur are:

- Some water has entered the drainage system through the interface between the sunroof hatch and car body
- The car is travelling at a speed of about 100 km/h
- The sunroof hatch is in a tilted position (ventilation position) or alternatively, any of the side windows is slightly opened

The specified driving condition is not in any way uncommon, especially not in Sweden as summers can involve rain in one moment and sunshine the next. If the speed of the car is reduced enough during the occurrence of the sound phenomenon it stops. However, the phenomenon might very well occur again if the driving speed is once again increased.

3.3 Short term problem solution

Some work has already been done by the engineers at Volvo Cars in order to correct the problem. They had to come up with a quick solution in order to be able to ship the new cars, since a non-shipping restraint was put on the cars until a solution was implemented.

Initial testing showed that the problem could be reduced by changing the position of one of the fastening points of the hose leading down from the sunroof frame and down to the drainage outlet in the engine compartment. This did not completely solve the problem but rather made the sound less obvious for the customers and made it more difficult for it to occur. Figure 3.5 illustrates the idea of the short term solution were the hose is positioned higher at the lowest clip position. Meanwhile the hose today is mounted in a new clip in this position.

Figure 3.5 – Illustration of new higher clip position

3.4 Initial requirement specification

In order to understand the product and its characteristics it is important to state the requirements that exist on the specific part. In this early stage of the project an initial requirement specification has been composed. During product development work the requirement specification is a “living” document. This means that it should not be considered as finished until the project is closed. New knowledge is gained and new requirements are identified throughout the development project and create the need to constantly update the requirement specification. Having a document that is up to date reduces the risk of missing out on important requirements that might be imposed on the component (Almefelt, Design Methodology: The Requirements Specification, 2009). The final requirement specification cannot be stated in this report since it contains classified information. Instead the requirements on the project and the concerned parts that have been stated along the way of this project by the authors of this master’s thesis are shown in Appendix A2. Volvo Cars different requirements on the drainage system have been translated from the Technical Regulation “Drainage system, openable roof system” (Dryselius, 2009).

In order to map the needs on the product from the perspective of Volvo as a customer, an affinity diagram was composed. The customer in this case is the Sunroof system group at Volvo Cars for whom the master’s thesis project is carried out. The Affinity diagram was composed from the issue of, “Which are the requirements on the drain plug?” and altogether seven sub headlines were found regarding the topic. For the complete Affinity diagram, see Appendix A3.

The needs identified through the affinity diagram were then used in a Kano model. The needs were sorted regarding the customers perception of them as “must be”, “more is better” or “delighters”. The characterisation helps with the weighting of the needs to know where to focus the work. The result from the Kano model is shown in Appendix A4. In this Case the customer is both Volvo Cars and Volvo Cars customers.

When the different needs have been characterised in the Kano model they can more easily be weighted. The weighting was performed in a requirement weighting matrix. The matrix weights each of the needs against each other to give them a priority number which then is used to give the need a weight. The weighting matrix along with the weight formula and the needs final weight are presented in Appendix A5.

3.5 Analysis of current solution

One of the most important parts of the problem solving process is to understand the actual problem. There are several different tools and methods connected to this described in the theory of the Six Sigma methodology. However, only a couple of these seemed suitable and were applied during the Define phase.

The first thing that was compiled was the Ishikawa diagram. This rather simple tool illustratively displayed several potential factors that could contribute to the problem with the unwanted sound phenomenon. The factors had been retrieved by conducting several shorter interviews, or rather discussions, with key personnel connected somehow to the designing of the drainage system, neighbouring systems (relative position in final product) and similar systems throughout the car. Also attribute leaders of the *NVH* (Noise, Vibration and Harshness) and *Water tightness* disciplines as well as a test engineer from Volvo’s Chemistry lab was involved in the discussions. By talking to key personnel from several different departments and within different disciplines a lot of knowledge was gained regarding what requirements and problem areas the drainage system had to cope with. Brainstorming was also used within the project team to come up with potential factors. The resulting Ishikawa diagram can be seen in Appendix A6.

Another useful tool that was applied was the FMEA. The analysis conducted included the drain plug and hose, both placed in the front end of the drainage system. The knowledge gained from the interviews/discussions was once again shown to be very useful, in this case when identifying possible problem areas. The FMEA also describes how these problems can affect different stakeholders, as well as the severity of an occurring problem. From this it was possible to identify which areas of the design that need special attention with respect to the occurrence of the unwanted sound phenomenon. Below follows a short list of the two most important attributes that the drain plug and hose has to cope with. The FMEA document in its full version can be found in Appendix A7.

- Prevention of stagnation of water in the system
- Cope with pressure differences (between top- and bottom end of front drain hoses)

The current solution was also analysed through observation, both on the actual system fitted in a car and in the virtual world as a DMU. These observational studies helped in getting a sense of how the system was fitted in the car, how it related to other systems and components in the car, as well as what space that was available for any changes of the components. The software used at VCC for DMU visualisation is integrated in the PLM software suite *Teamcenter* provided by *Siemens.*

The assembly process of the drain hose was analysed by observational studies at VCC´s assembly plant, called factory C, at the VCC production facilities in Torslanda. This was done in order to identify possible causes of unwanted variation that could affect the performance of the drainage system. A result from this analysis was that a certain over-length is used for the hoses to ease the assembly process. Where this over-length is placed can differ a bit between assembly workers and consequently contributes to some variation.

4. Measurement and analysis of data

To be able to assess the problem at hand a lot of data had to be collected and analysed. The measure phase of the DMAIC process includes the data collection needed for the improvement project. The first step of the measure phase is to make an assessment on which types of measurements that need to be carried out, who should do the measurements and so forth. It can be relatively easy to gather lots of information and data, the difficulties lie in how to manage and analyse it. The next step in the DMAIC process is the Analyse phase where you interpret all the data. This chapter includes both the Measure and Analysis phases as these are carried out more or less in parallel.

In order to structure the measure and analysis phase a data collection plan was created. The plan lists which data that needs to be collected, why it is needed, who should be responsible for the data collection, how it shall be collected, when and where. The data collection plan makes it easier to organise the data collection procedure and makes sure that all involved are aware of what shall be accomplished. The collection plan is attached in Appendix A8.

4.1 Benchmarking

By investigating the solutions that competitors have used in their corresponding drainage systems new knowledge on how to solve the problem could be acquired. In order to do so reverse engineering practises have been applied and a number of competitor solutions have been looked into. The database called *A2MAC1* has been used for this purpose. It is a database serviced by an independent actor listing products in the automotive industry with detailed pictures and information on how the products are built up (A2MAC1, 2011). Further, the present solution was compared with pre-existing products from Volvo cars.

When investigating new solutions a good starting point is to search among current solutions on the market, both internally and externally. Internally at Volvo cars two other systems use different drain plugs to evacuate water. These use non-return valves with both soft and hard materials. The harder plastic ones are made as two parts, one that collects and steer the water towards an opening where a hatch, connected by hinges, open and close itself when water is exiting the water evacuating system, see Figure 4.1 for two examples. Some of these have a small tooth on the edge where the hatch closes itself, which prevents it from closing entirely and thereby minimises risk of freezing.

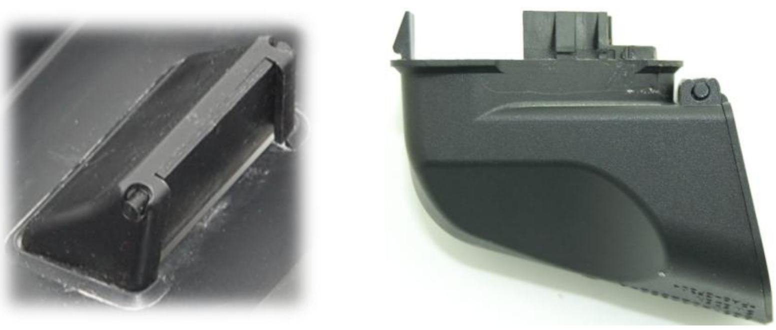


Figure 4.1 - Hard plastic water evacuating. Left - Placed on plenum tray. Right - Connected to lower plenum area.

The softer rubber plugs are made as single pieces with a non-return valve that opens and closes itself when water enters it. Figure 4.2 shows two examples of soft rubber drain plugs.

Figure 4.2 - Soft rubber drain plugs. Left: Soft non-return valve, bigger. Right: small drain plug, also called Y0 since placed in Y=0 according to vehicle coordinates

Other competitive car manufacturers' solutions have also been studied, for this purpose the benchmarking service provided by the A2MAC1 webpage have been used. Here it could be seen that most competitors use very similar solutions to the ones Volvo Cars have, Figure 4.3 shows three different competitor solutions.

Figure 4.3 – Pictures of competitors different drain plugs. Left - Volkswagen Eos. Centre - Volkswagen Phaeton. Right - Audi A4

Not only drain plugs were investigated, also different hoses and routing of these were studied. It was shown that most competitors used very similar routing, although some had more interesting ones, for instance through the inside of the A pillar.

Drainage solutions in other areas outside of the automotive industry were also studied. Examples of this are medical applications, AC systems and marine applications. Patent databases were also looked into for other drainage solutions; see Figure 4.4 for drainage examples.

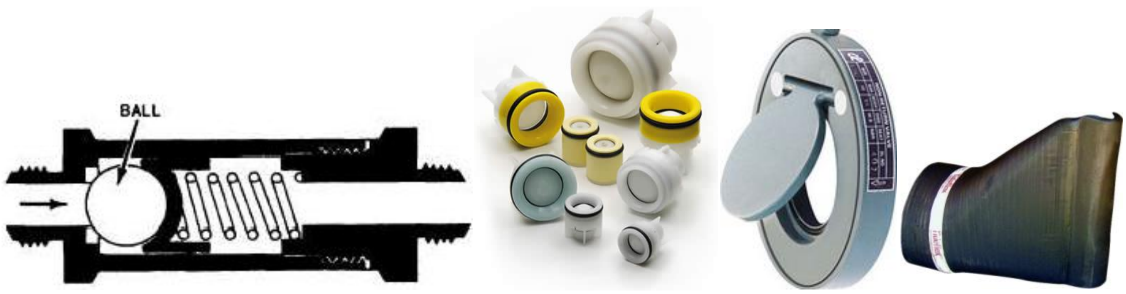


Figure 4.4 - Different drainage solution. From left to right: 1 and 2 - Different non-return valves with ball solution. 3 - Hard metallic non return valve with hatch. 4 - Soft drainage with twisted lip to prevent water from entering.

Since one problem area to consider is the growth of microorganisms (microorganisms can grow inside of the drain system and clog it) different surface coatings and more innovative technologies were studied. Teflon coatings exist that minimise the risk of water drops getting stagnant in the system and also prevent microorganisms to grow on the side walls. Another interesting finding was a silver-Ion technology which is used in shower hoses for instance. This technology kills the microorganisms and makes it impossible for them to grow, see Figure 4.5.

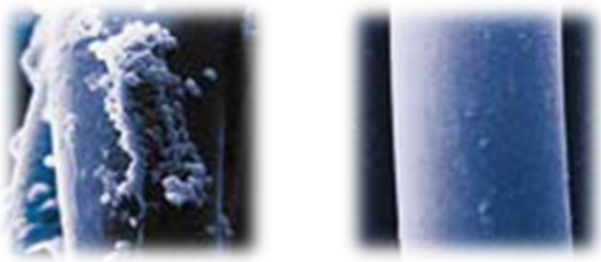


Figure 4.5 - Pictures of microorganisms growth in hoses. Left picture: surface without Silver-Ion treatment. Right picture: material with Silver-Ion technology. (Hansgrohe, 2002)

4.2 CFD calculations of pressure differences in front drain hoses

During test drives with a car known to have the issue of the unwanted sound phenomenon it was shown that air was blowing through the drain hose in the opposite direction of the water flow. This was suspected to appear due to pressure differences between the areas in the lower and upper end of the hose. Since this hypothetically could lead to water going up through the hose, if the pressure differences is large enough, it was considered to be important to investigate further.

The department for CFD simulations at VCC was contacted and asked if they could support with simulations. A simplified model was created by CFD engineer Torbjörn Virdung and he made simulations of the pressure differences in the drain hoses on an S60, the experiment description of the simulation is shown in Appendix A9. Figure 4.6 shows an overview picture of the results from the simulation. Note the colour coding just below the windscreen, the dark shaded colour represents the so called plenum area of the car (in which the drained water exits the system). It is also in this area that the AC system collects air for the interior climate.

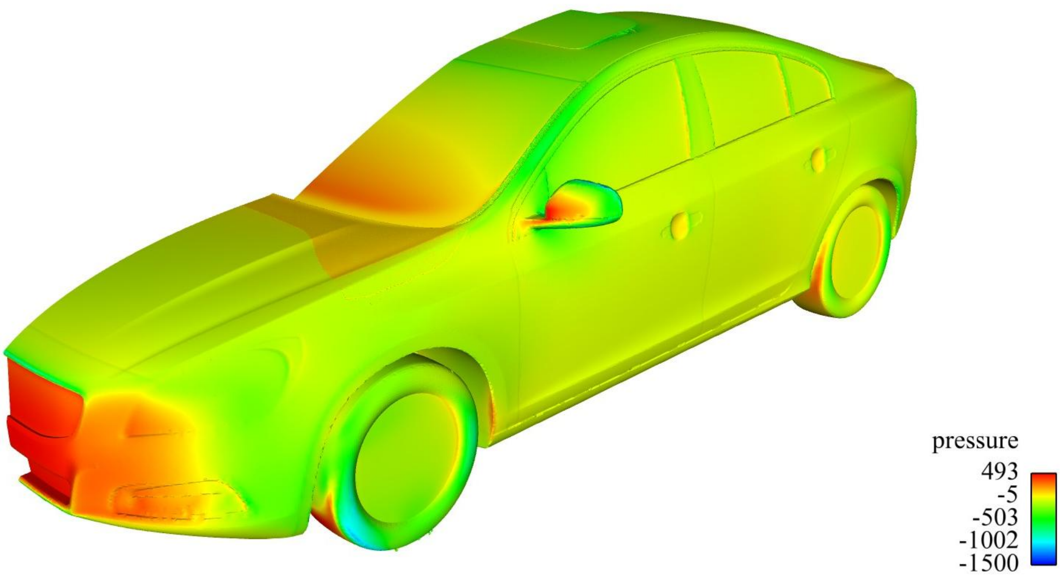


Figure 4.6 - Results from CFD simulations showing pressure differences on an S60. The scale is in Pa

The model created had to be simplified though, since time and resources were limited. The model included a simplified interior represented by a box inside the vehicle, the air intakes on the plenum cover are meshed in reality and they were represented as larger holes in the model. The plastic covers preventing fingers from entering the gap between the sunroof and car body were not present in the CAD model. The "box" representing the interior of the car was simulated as completely airtight, this is off course not the case in reality. The plenum area was simplified to allow calculations. The plenum area is one of the most difficult ones on the car to simulate (Virdung, 2011) hence, some components in this area had to be removed. In order to save computational time only half of the vehicle is represented in the simulations. This is the way the engineers at VCC usually run their simulations.

Either way, none of the simplifications was considered to be critical for the end result (Virdung, 2011). It would still be good enough to show if pressure differences were present or not. The driving scenario simulated was at the speed of 100 km/h, the same speed in which the unwanted sound phenomenon is known to occur. Figure 4.7 shows the inside of the car with the simplified interior, the sunroof system and the plenum area.

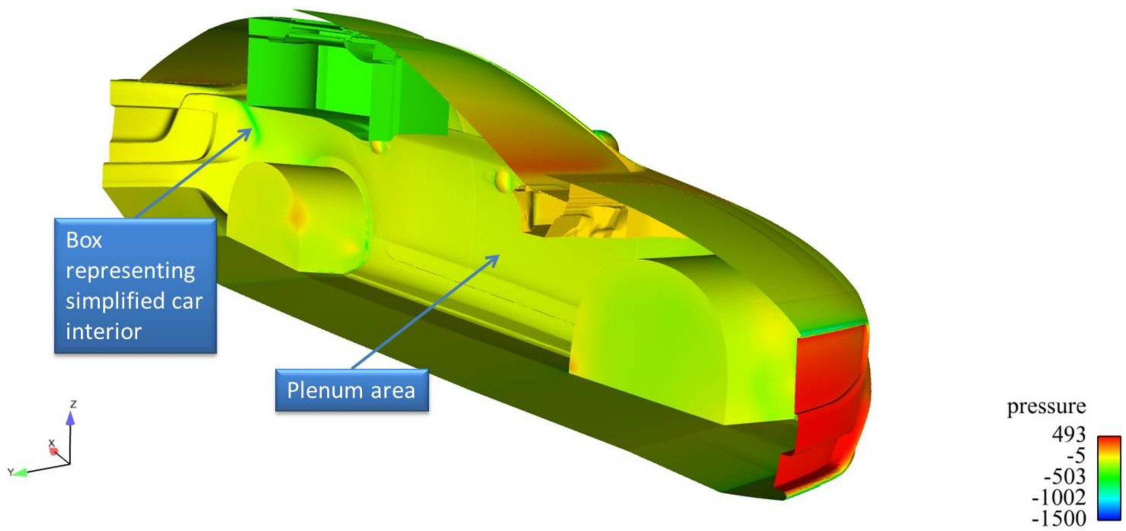


Figure 4.7 - Illustration of simplifications made in the interior

The results showed, as suspected, that there were quite large pressure differences between the top- and bottom end of the front drain hoses, see Figure 4.8. The pressure scale illustrated in Figure 4.6, Figure 4.7 and Figure 4.8, is relative to normal atmospheric pressure and measured in Pa. The simulations showed that there was a pressure difference as high as 354 Pa (ΔP) between the top- and bottom end of the drain hose (Virdung, 2011).

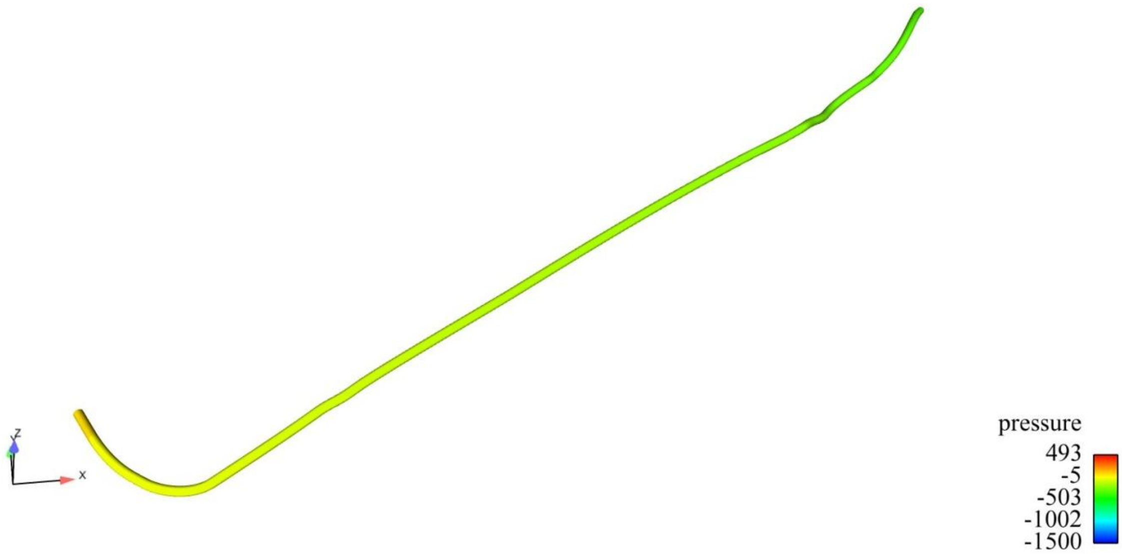


Figure 4.8 - Illustration of pressure differences on left drain hose

The results from the simulations could be used to calculate how much water that theoretically could be stagnating in the drainage system as a result of these pressure differences, the hose inner diameter is 9 mm. Equation 4.1 was used for this purpose (Virdung, 2011).

$$\Delta P = \rho \times g \times \Delta h \qquad \textbf{Equation 4.1}$$

$$\xrightarrow{yields}$$

$$\Delta h = \frac{\Delta P}{\rho \times g} = \frac{354}{1.0 \times 10^3 \times 9{,}82} = 36 \ [mm] \qquad \textbf{Equation 4.2}$$

Equation 4.2 represents the calculation of the water pillar which could be stagnated in the system. The length of 36 mm could be kept stagnating in the drain hose when driving at the speed of 100 km/h. This means that a water-pillar smaller than this would travel upwards in the drain hose while driving at 100km/h. It also shows that the differences in pressure make the air flow in the opposite direction of the water flow (upwards in the drainage system). Equation 4.3 shows the amount of water that a 36 mm water pillar stagnating in the drain hose corresponds to.

$$\pi \times (4{,}5 \times 10^{-3})^2 \times (3{,}6 \times 10^{-3}) = 2{,}290 \times 10^{-6} \, m^3 = 2{,}290 \ [ml] \qquad \textbf{Equation 4.3}$$

4.3 DMU measurements

In order to make an assessment regarding how well the current solution fulfilled the requirements stated in the *Technical Regulation* (Dryselius, 2009) regarding the sunroof drainage system, a set of measurements were performed in the DMU environment. The measurements involved the angle of the hose inclination at the lower bend of the drain hose, the space that was available for the drain plug as well as the inclination angle of the hose with the new clip position. Figure 4.9 shows the angle of the hose inclination. It can be seen that the inclination angle that should be negative relative to the horizontal plane is actually 3,421° in the wrong direction. This makes the area at the bottom of the drain hose a high risk area for water to get stagnated.

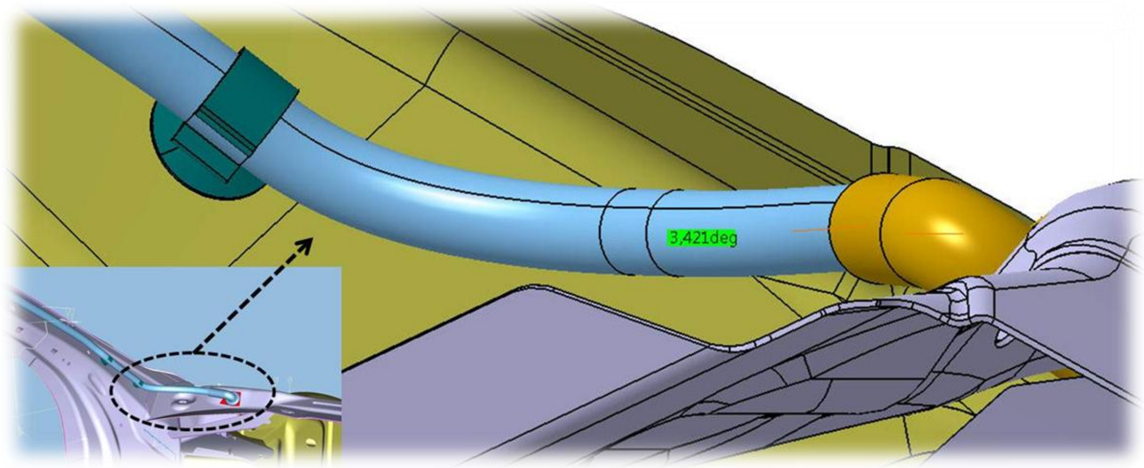


Figure 4.9 - Inclination angle at the lower bend

The amount of space that was available for the drain plug and hose in this area was also looked into. This was primarily done in order to gain knowledge on how much space that could be used for a potential new solution of the drain plug and also to assess if it would be possible to change the position of the lower clip to increase the inclination. It was shown that when the hose was moved by using the new clip position the inclination of the hose was altered to a more suitable -2,365°, relative to the horizontal plane. The new clip position drastically changed the hose inclination for the better but it was still far from the -7° stated in the *Technical Regulation*. Figure 4.10 shows a comparison between the original clip position and the new modified position. The modified position is the one currently being implemented in production at VCC to decrease the risk of the unwanted sound phenomenon to occur.

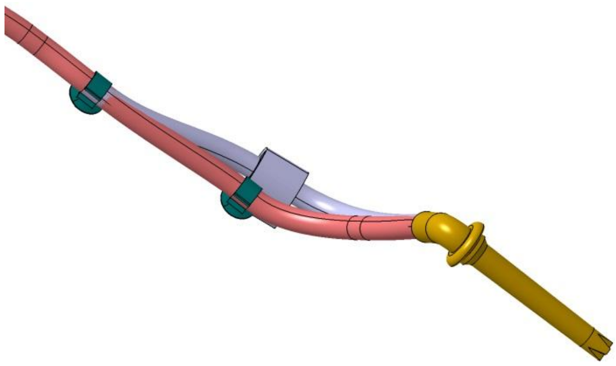


Figure 4.10 - Comparison between the original clip position (red hose) and the new modified position (grey hose)

Another place on the drain hose were the inclination was found to be unsatisfactory was at the roof position, just after the connection to the sunroof frame. It was found after making measurements in the DMU that the inclination here was 1,161° upwards, relative to the horizontal plane, see Figure 4.11. This area could also suffer from the risk of creating a water trap.

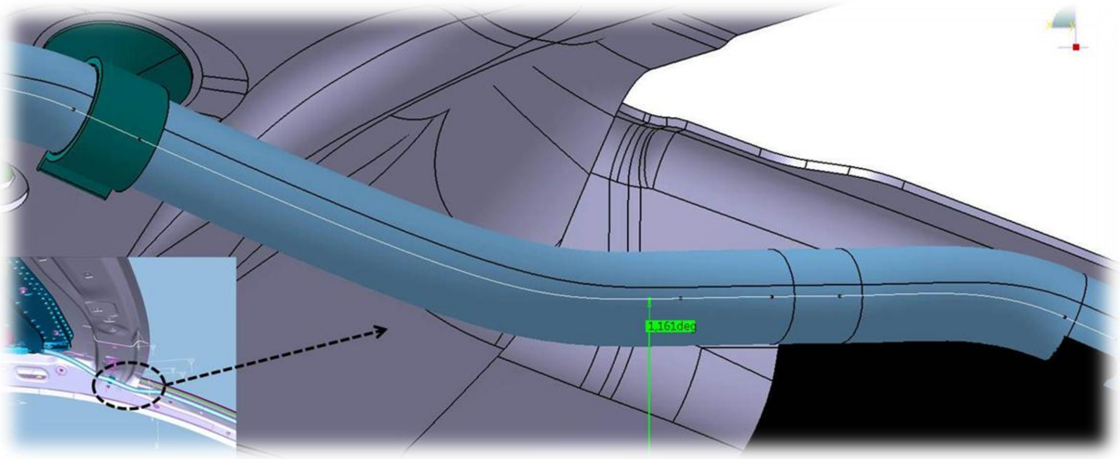


Figure 4.11 - DMU of potential upper water lock

These results pointed out the risk of having two water traps in the drain hose. However, it needed to be investigated if reality corresponded to the DMU to determine if this was indeed a real problem in the physical vehicles.

4.3.1 Tests with transparent hose

Since the inclination of the drain hoses did not fulfil the TR it was of interest to see where the water got stagnant in the system. This was done in two different ways, first the original hose and drain plug was mounted in an empty car body. Water was poured into the drain hose and a fibre optic camera was used to see where water got stagnant, see Appendix A10 for experiment description. It was sometimes hard to see with the fibre optic camera and therefore a transparent hose was mounted instead. This showed where water was trapped a lot clearer. However, what needs to be taken into account is that the transparent hose had an inner diameter of 12 mm, instead of the original 9 mm and the inner surface may also have differed to some extent between the hoses. Either way the two experiments showed that small drops were present along the hose at the two critical positions. The top water trap had large drops present, see Figure 4.12, while the lower one had a larger amount of accumulated water at the area with the lowest inclination, see Figure 4.13.

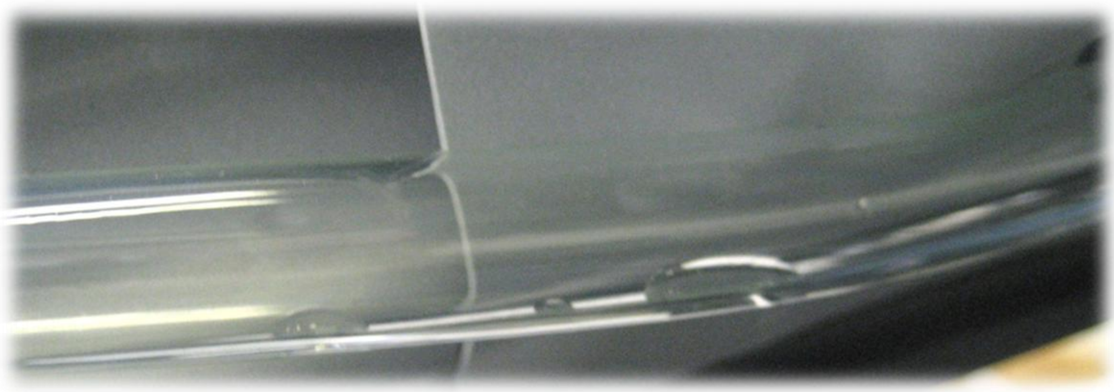


Figure 4.12 - Upper water traps with small drops of water

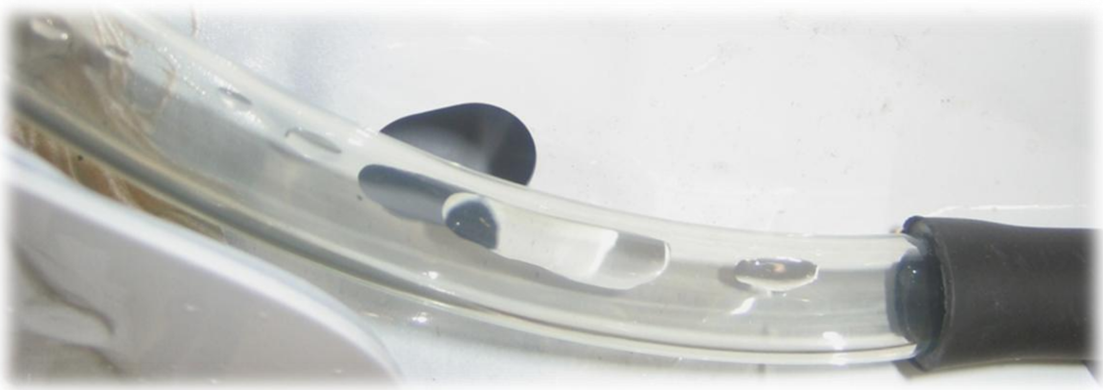


Figure 4.13 - Lower water trap with larger water piles

Since it was interesting to see how the water is moving in the hose while the sound phenomenon occurs, a transparent hose was mounted in a car which later on was test driven. The A pillar cover was left off in order to make the hose visible during the whole test run. It was shown that the water is climbing the hose, in thin horizontal planes. The sound phenomenon occurs when the moving water planes burst. It was during the test drive also seen that the water in the upper water trap did not affect the sound phenomenon. It was therefore later on decided that this one was not to be changed.

4.4 Measurements of water stagnation

Since stagnated water in the drainage system had been identified as a critical factor for the sound phenomenon to occur, it was concluded that it would be wise to measure the amount of water that gets stagnant. How this was to be done was discussed with one of the Six Sigma specialists at VCC, in order to make sure that a proper measurement method would be used. The most important aspect to investigate was how process variance could influence and roughly how many measurements that had to be carried out.

4.4.1 Measurement system analysis

The proposed method for the analysis was to measure how much water the system would let through when adding a specified amount of fluid at the sunroof end and then measure how much of it that came out at the lower end (the so called cold zone, engine compartment).

When conducting this type of experiment the results are always influenced by different amounts of variation. This variation could originate from the process being measured itself, but more importantly it could be influenced by which operator is conducting the measurements, what instruments that are used and so forth. The most important part is to make sure that the measurement system itself contributes less to variation than the process does. For a measurement system to be regarded as appropriate its contribution to variation should be at most nine percent of the total variation and less than one percent to be regarded as "excellent" (Six Sigma Academy, 2002). If the measurement system variation should be higher than that of the process, it would be impossible to draw any correct conclusions from the measurements.

The Measurement System Analysis (MSA) was carried out by having three operators pouring five different amounts of water (2, 4, 6, 8 and 10 ml respectively) into the system; see experiment description in Appendix A11. The collection of water at the lower end of the system was carried out during two minutes and thirty seconds. The amount of water was then measured using a graduated cylinder. The cylinder was also used to pour water into the system; the collection was however done with the help of a glass cup. This water was then poured into the graduated cylinder and the collected amount of water was measured and recorded in a measurement protocol, see Appendix A12. The car model that was used for the MSA was a Volvo XC60. It is worth mentioning that the choice of car model does not influence the measurement method is worth mentioning, since they have the same drain hose and plug.

The results from the MSA was analysed using the computer software *Minitab.* This software has an array of built in tools for statistical analysis. Minitab was also used to conduct an ANOVA (Analysis of variation). This showed that the contribution to the total amount of variance from the measurement system was merely 0,95 percent, see Appendix A13. This would imply that the measurement system used could be considered excellent for the planned analysis. Further, in order to establish how many samples that would be necessary to measure during the actual analysis of the S60 and V60 models, a so called Power and Sample analysis was carried out. This unfortunately has to be done after measurements have been carried out, but nonetheless it is useful as the number of samples can be increased if shown insufficient. The results from this analysis showed that a number of six cars would be enough to conduct experiments on, this was also the number used in the actual water stagnation measurements. The results would then have a margin of error of at most ± 0,20 ml.

4.4.2 Measurements of water stagnation in S60 and V60

Since the measurement method had shown to be satisfactory the actual water stagnation measurements could be carried out as planned. As mentioned above, measurements were carried out on six different cars, three S60 and three V60. The models are identical from the B pillar and forward and should show similar values in amount of water getting stuck in the drainage system. Measurements were carried out by two operators and both the right and the left hand side was analysed. Also, two different hose positions were measured, the original position and the modified position, see Figure 4.14 for hose positioning and Appendix A14 for the experiment description.

Figure 4.14 - Pictures of different drain hose positions. Left - Original position. Right - Modified position

All raw data was written down in protocols similar to the MSA protocol, see Appendix A15. Once again, Minitab was used to analyse the result of the measurements. The standard deviation, variance and mean values were calculated, as well as the mean of all the measurements for the left and right hand side both for the hose in original position and modified hose position. The variance in these measurements was shown to be much greater than when identical measurements were carried out on the XC60. When applying a Power and Sample analysis on these measurements it suggested a sample size of over 70 vehicles. This was of course neither feasible nor necessary in order to show the results needed to illustrate a trend. Six vehicles were considered enough to measure since a clear trend could be seen in the results. It showed that the amount of water that was stagnating in the system decreased when the hose was moved to the modified position. It also showed that some water still got stuck, even with the modified hose position, about 2 ml. Table 4.1 shows the mean values in millilitres of water that was collected after passing through the drainage system of the six vehicles tested. Here it can be seen that all the values get better in the modified hose position, except in one case where they actually get worse. This is assumed to depend on the fact that the test vehicles available at VCC are often from pre-production series and hence, might differ a bit from the final product.

Table 4.1 - Mean value in millilitres of collected water from water stagnation measurements

	Hose position			
	Original right	Original left	Modified right	Modified left
Car model	[ml]	[ml]	[ml]	[ml]
S60	8,54	4,31	8,54	7,88
S60	6,84	6,76	8,46	8,53
S60	6,71	6,67	6,85	6,41
V60	3,06	7,06	6,97	8,95
V60	7,44	7,50	8,91	8,50
V60	7,44	1,84	9,02	7,16

It can also be seen that the variance of the drainage process is quite large as compared to the mean values. This indicates that the function of the system can differ to some extent between different versions of the same car. This implies that the unwanted sound phenomenon might be worse in some cars than others. A summary of the statistical calculations carried out in Minitab can be seen in Appendix A16.

4.4.3 Evaluation of surface tension contribution to variance

Since the spread in the distribution of the collected water in the water stagnation measurements was very large, it was discussed if it might have to do with the surface tension. The surface tension was evaluated by adding washing-up liquid to the water before it was poured down the drainage system. The tensides in the washing-up liquid would then reduce the surface tension of the water, making drops of water less prone to attach to the inside of the drain hose. The experiment description can be found in Appendix A17.

From the tests it was shown that the adding of washing-up liquid reduced the spread but only slightly increased the amount of water that was drained. This showed that the surface tension of the water only contributed to a small amount of the variation and could be considered as negligible. The measurement data is displayed in Appendix A18.

4.5 DoE at proving ground Hällered

In order to analyse the effect on the unwanted sound phenomenon that different parameters could have a DoE experiment was conducted. The factors that were looked into were identified with the aid of the Ishikawa diagram constructed at an earlier stage (see chapter 3.5 Analysis of current solution). Due to limitations of the possibilities to do modifications on the car, it was not possible to conduct all tests that beforehand were considered interesting. For instance, it was not possible to exchange the current drain hose with a hose with larger diameter. This would require the removal of components that would make the car unsafe to drive. Instead, a compromise with regard to which factors that was analysed had to be made. The following factors were considered as interesting, as well as feasible, to investigate:

- Inclination of drain hose
- Size of drain plug end opening
- Speed of the car

The experiments were carried out at VCC´s proving ground Hällered. The car that the experiments were carried out in, a Volvo S60, was driven around an oval test track and one experiment run corresponded to one lap around the test track, the experiment description can be seen in Appendix A19.

The prerequisites were that the sunroof had to be in a tilted position and there had to be water added to the drainage system. The experiment design used was a full factorial design with three factors at two levels, giving a total of eight experiment runs. The experiment design table is displayed in Appendix A20 along with the results. The experiment design was created with the aid of the software Minitab which was also used to calculate the effects on the output. The choice of factor levels is displayed in Table 4.2.

Table 4.2 - Factors and the levels used in the experiments

	-1	1
Inclination:	Placed in clip	Placed beneath clip
Speed:	80 km/h	110 km/h
End opening of drain plug:	Original opening, Cross shaped	Widened opening, round

Each experiment run was followed by a modification of the parameters and the adding of 50 ml of water to the system. The run order was in to as large extent as possible randomised, it was not possible to make it completely randomised though, as a widened drain plug opening required that the drain plug had to be cut open. It was not possible to exchange the drain plug in between experiment runs since it required too much modification to the car. Hence, some alterations to the run order were made but the influence this might have had on the results is considered to be negligible. Since each test run was started from a platform higher than the test track some water leaked out of the system when entering the track. In order to minimise the water which left the system before start the two inclinations of the hose were chosen to be hose placed in lowest clip and hose placed beneath lowest clip.

The output of the process to be measured, in this case the noise level of the unwanted sound phenomenon, was graded according to a four level scale. The noise level was assessed subjectively by the three engineers conducting the experiments, the authors of this master's thesis report along with one of the development engineers at VCC. The assessment scale is displayed in Table 4.3.

Table 4.3 - Assessment scale of noise level

Grading	Assessment scale
0	No Sound
1	Weak sound
3	Intermediate Sound
9	Loud Sound

The result of the experiments is shown as a Cube plot in Figure 4.15. This shows that the inclination of the hose has the largest effect on the unwanted sound phenomenon. The other factors do not seem to influence to any larger extent. It should be taken into consideration when discussing these results that no proper instrument was used to measure the sound level. This might have given slightly different results as wind noise negatively affected the possibility to hear the unwanted sound phenomenon negatively, at the higher speed setting. It is also difficult to assess if there is any difference in noise level between experiment setups if this difference is relatively small.

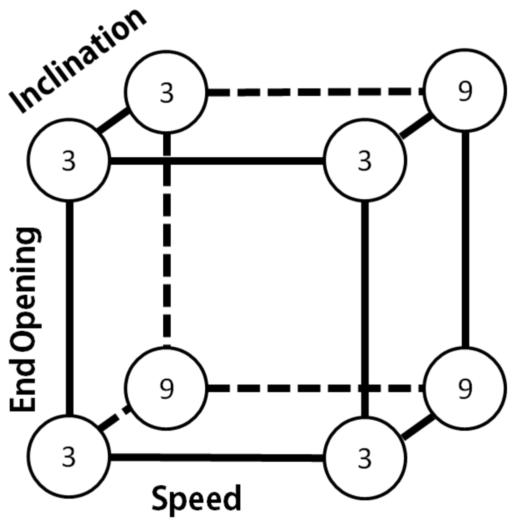


Figure 4.15 - Cube plot of results from DOE

The fact that the inclination of the drain hose had great effect on the noise level was an expected result that could now be verified through the DoE approach. The effects of the other factors are something that would require more investigation before any conclusions can be drawn.

4.6 Ad hoc tests at proving ground Hällered

After the DoE session at the proving ground Hällered some additional, more ad hoc, tests were carried out. This was in order to investigate how different “solution concepts” would affect the unwanted sound phenomenon and see which ones that would be promising to conduct further testing on, see Appendix A21 for experiment description. The “solutions” that were tested were as follows:

- Back valve, different variants
- Re-routing of hose in plenum area
- A sound trap

The tests had some limitations since the entire drain plug could not be changed as it is situated in a position behind the dashboard, making it hard to remove. Therefore, focus was on the end of the drain plug which was altered through different couplings to other drain plugs and modification of these.

The test was performed as a worst case scenario with information acquired during the DoE, which meant that the hose was placed beneath the lowest clip in the A pillar. The idea was that if the phenomenon could be eliminated during a worst case scenario, it would be eliminated in every other case as well. In addition, with those solutions resulting in no sound phenomenon the driving speeds were alternated in series to trigger the sound to emerge. In Appendix A22 a short list of the different tests performed and their results can be found.

By analysing the results some relations could be deduced. It was concluded that it does not matter where the water is drained in the cold zone, the phenomenon will still occur. This was shown by leading the plug to different locations in the cold zone and also through previous tests performed by the Solidity department at VCC. It was also shown that the under pressure itself is strong enough to trigger the phenomenon. The sound can however be minimised or even eliminated by turning the AC to a maximum. The AC air intake is positioned in the cold zone and when it is used it minimises the over pressure that is present here. It was shown that if the air flow into the hose is stopped, the phenomenon will be eliminated.

To stop the air flow but still enable the water to enter the plenum tray, a non-return valve can be used. During the tests it was shown that it is critical that the non-return valve can close itself entirely during driving. If the plug has a lid to cover its end opening, this needs to be light enough to enable the backpressure to suck it into closed state during driving. Because of this the drain plug end hole has to be entirely closed. It was shown that even a small opening would enable the unwanted sound phenomenon to occur.

4.7 Cold climate tests

Since it is vital for the drainage system to be able to drain water in any climate it was important to ensure that the drain plug would not freeze at low temperatures and thereby disable drainage capacity. For this purpose a series of tests in a cold climate chamber were carried out. The experiment description for the cold climate tests can be found in Appendix A23.

A climate chamber set to minus 5°C was used to perform the tests. A fixating test rig was built up to ensure that the test conditions would be the same for each test as well as similar to the position in the cars. The test rig is displayed in Figure 4.16. During the tests the different components were attached to the test rig which was then placed in the climate chamber.

Figure 4.16 - Test rig for climate tests

Before each test run water was poured through the drainage system to enable freezing. The test rig was then placed in minus 5°C for at least five hours to ensure that the water froze. After the test cycle water was once again poured through it to investigate whether the drain plug was frozen tight or if it still drained water.

The stated temperature and test sequence were agreed upon together with Göran Nyman (attribute leader water tightness, VCC) and Joakim Dryselius (Technical expert, Roof systems VCC). It was decided to test realistic cases, which could occur when a customer is using the car. One scenario covered would be if rain during the day is followed by a cold night. The temperature would then drop to below zero degrees Celsius, allowing the water stagnated in the system to freeze and clog the drain hoses. If it would rain again the next day there could be risk of flooding of the drainage system. Another scenario would be if one should wash the car during wintertime in combination with ice clogging the drain hoses.

Four different drain plugs were tested, three from Volvo Cars and one from a competing car manufacturer. It was shown that each of the tested drain plugs drained water also at the test scenario. The plugs froze to some extent but opened up entirely when water from the drain hose was pressing against them. The result from the tests is found in Appendix A24.

4.8 Summary of the measurements and analysis

Along the measure and analysis phase the problem regarding the gurgling sound phenomenon became a lot clearer. The aspects and parameters that were identified as critical for the problem to emerge are illustrated in a fault tree analysis, see Figure 4.17. To start the gurgling sound two main things are needed, first of all there needs to be stagnant water in the drainage system. Secondly, there has to be an air flow upwards through the drainage system. This is created through a pressure difference between the cold zone and the sunroof. To get enough stagnant water in the drainage system the drain hose inclination needs to be low as well as there has to be some water that has entered any of the two front drain hoses.

When the stagnant water is present there needs to be an air flow through the drain hose. To achieve an airflow upwards through the drainage system there is a need for an under pressure at the hose inlet, as well as an overpressure at the hose outlet. The under pressure at the hose inlet is built up through a combination of high speed of the vehicle and a tilted or opened sunroof, alternatively an open side window. The overpressure is built up due to high speed of the vehicle and a low rotating speed of the AC fan. The AC inlet is placed in the cold zone and will reduce the pressure in this area.

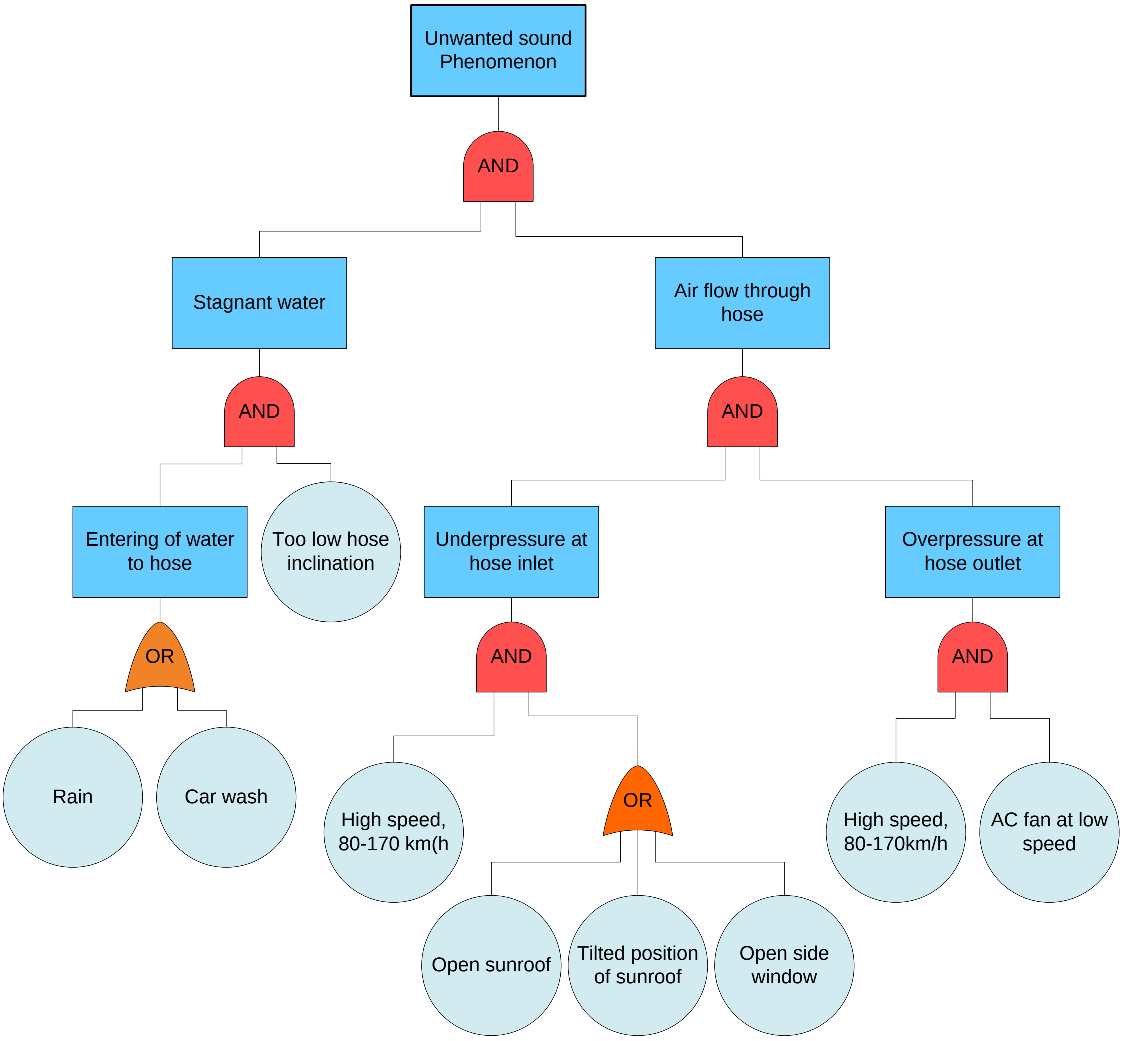


Figure 4.17 - Fault tree analysis of unwanted sound phenomenon

4.8.1 Potential future problems with current solution

The problem with the present drainage system is not only the gurgling sound phenomenon but also that the low hose inclination which might become a problem with regard to dirt build-up over time. Sand and other small particles access the system and might get stuck where the inclination is too low to make the water push the particles out. This will over time lead to that the amount of dirt can increase until it clogs the hose with flooding and water entering the car interior as a result. Dirt can already today clog the drain plug when fir needles and leaves get stuck in the narrow opening of the drain plug end hole. Microorganisms are another problem that needs to be taken into consideration as they can start to grow at the opening of the drain plug and eventually clog the drainage.

5. Improve – Development of new concepts

The improvement phase is the most creative phase for the product developer during the DMAIC process. It is during this phase that new concepts are developed and evaluated and the most promising solution proposals are brought further into the development funnel. This chapter describes this process and the results that came out of it.

During the development of new concepts the different ideas are looped several times through different screenings. The screening process can also be illustrated by the development funnel. The funnel starts with investigations of many concepts which over time are screened throughout the loops in the process. Figure 5.1 shows an illustration of the development funnel used in this project. (Wheelwright & Clark, 1992).

The idea with the screenings is to be able to rule out concepts along the way in order not to use resources on inferior concepts. The screening itself can be performed in different ways and with focus on different parts.

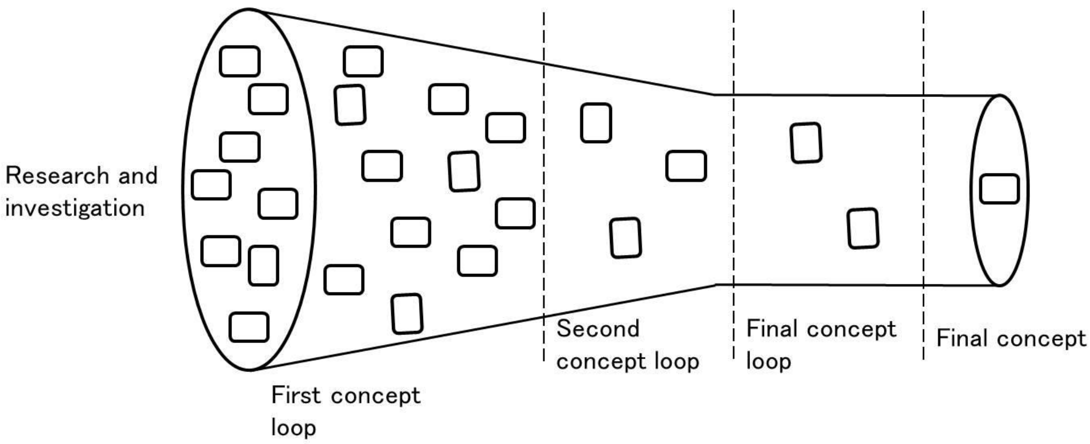


Figure 5.1 - Illustration of the development funnel

From the fault tree analysis illustrated in Figure 4.17 the focus areas on the new concepts should be put on the water in the system as well as the airflow throughout it. The unwanted sound phenomenon can be eliminated by removing any stagnating water in the system, by disabling the water from moving or by disabling air to pass the inside of the system.

5.1 First concept loop

During the first concept loop general concepts for the solution of the unwanted sound phenomenon was created and evaluated. At this stage the concepts are very open and on a high level. The ones not fulfilling stated demands or those that are proven not to solve the problem will be discarded from further development in a first screening.

5.1.1 Brainstorming for new concepts

In order to find potential new concepts that the new solution could build upon a brainstorming session was arranged. Attending this session was a few people from the Roof systems group at VCC that had earlier in one way or another been involved in the development of the current drainage solution in one way or another. Further, one specialist in fine mechanics and Six

Sigma attended. From the brainstorming session some basic concepts were defined. These concepts are described in this section of the report and are also illustrated in a Morphological matrix found in Appendix A27.

Hose mounted in modified clip

By modifying the clip in the bottom position of the A pillar (closest to the drain plug) the inclination of the drain hose could be increased. This would lead to less water stagnating in the system and hence, a possible reduction or even elimination of the unwanted sound phenomenon.

Hard fixed plastic hose with forced inclination

In order to enable all of the water to be drained the inclination angle must be larger than in the current solution. A better inclination angle can be achieved through a hard fixed plastic hose, which forces a specific inclination at the critical part of the drain hose.

Rerouting of hose

Since the sound phenomenon occurs when there is stagnant water in the drainage system one of the methods for removing the problem is to drain all of the water. All of the water could be drained through rerouting of the hose to improve the inclination angle. The rerouting includes more drastic solutions where the exit point of the drain plug would be changed.

Bigger hose diameter

If a large enough hose would be used the pressure difference inside of it could be minimised and make it difficult, or depending on size even impossible for the water to climb the hose. Thereby the unwanted sound phenomenon would be eliminated.

Hose inner structure with smaller canals

The sound phenomenon occurs when water is climbing inside the hose and the surface tension bursts. The idea with the inner canals is to spread the water and prevent it from climbing in the same way as in a regular hose.

Ribbed/bellowed inner structure of hose

A different inner structure of the hose could potentially make it harder for the stagnating water to move in the wrong direction within the hose. This could in turn remove the gurgling sound and solve the problem.

Hose with inner spiral

A supplier of automotive drain hoses offers a product with a spiral structure within the drain hose. This has proven to reduce road and engine noise and could potentially be effective against gurgling noise as well.

Low friction treated inner surface of hose

By applying low friction treatment on the inner surface of the drain hoses it would be possible to reduce the risk of having water stagnating within them. This would lead to a reduction of the risk of the unwanted sound phenomenon to occur.

Rubber bulb

The water is able to climb due to the high pressure difference that is present along the hose. One way of preventing the water from climbing is to enlarge the hose, through a bigger rubber bulb, at a certain critical point to minimise the pressure difference in the specific area.

Soft non-return valve

The sound phenomenon needs air flow through the hose to enable the water to climb. The pressure difference inside the hose can be disabled through a soft non-return valve which closes tight while driving. The idea can be integrated either in the drain plug or at the hose water inlet at the top.

Hard non-return valve

Just like the soft non-return valve the idea is to close off the air flow throughout the hose. A hard lid is used to close of the drainage system to the surrounding air pressure and flow. In this case the lid is a loose part which needs to be connected to the system though hinges. The idea can be used both at the drain plug as well as at the water outlet in the sunroof frame.

Non-return valve which closes when pressurised

A special kind of non-return valve could be used which is fully open in its standard position. When the pressure difference between the top- and bottom end of the drain hose is increased, it will force the valve to close and hence, completely remove the pressure difference that is essential for the gurgling noise to occur.

Larger water lock

Since there exists an upper boundary on how much water the air flow through the hose can carry, one idea is to make the routing of the drain hose worse and in this way enable a big water lock to form. The idea is that the water lock would carry enough water to disable it from moving upwards through the drain hose.

Electrical non-return valve

As the previous mentioned non-return valves, this one uses the same principle of shutting of the air flow through the hose while driving. The major difference is that this return valve should be electrically controlled. When driving at high speeds the valve should be kept shut and when speed is decreased or at standstill the system would be opened again.

5.1.2 Elimination matrix for new concepts

The concepts from the brainstorming and morphological matrix were placed in an Elimination matrix. The matrix was used for an initial screening of concepts in order to remove the ones shown not too meet certain criterions. The different concepts were evaluated with regard to solving the main problem, component requirements, compatibility, reliability, cost efficiency and the information possessed regarding the concept. In Appendix A27 the Elimination matrix is illustrated and the decision process is briefly described. The eliminated concepts were:

Hose mounted in modified clip – Eliminated because the problems could not be solved during a series of test runs performed with different clips.

Hard fix plastic part with forced inclination – Eliminated because the idea would not work. The decision was taken after a series of test runs with different clips where it was shown that even with the best possible inclination in this area the sound phenomenon could not be eliminated.

Re-routing of hose – Eliminated since larger modifications on the affected car models would not be accepted since they are in production. There is no path for re-routing available today that would work without making larger modifications to the car.

Bigger hose Ø – Eliminated since the size of hose inner diameter required to eliminate the sound phenomenon would not fit in current hose routing. The hose would be too large.

Low friction treated inner hose surface – Eliminated since the concept most probably would not eliminate the sound phenomenon and would be too expensive.

Larger water lock – Eliminated since there could be problems in colder climates with icing. Also, dirt could get stuck in the water lock and over time disable drainage though the hose.

Electrical non-return valve – Eliminated because the concept is too complex for this application and would be too expensive.

5.1.3 Pugh screening for new concepts

In order to construct entire drainage solutions to evaluate in the Pugh matrix the concepts that remained after the Elimination matrix were combined in different sets. The different combinations are mentioned in Appendix A29 before the evaluation in the Pugh matrices. The combinations are constructed with the morphological matrix as aid, with one concept chosen on each row. Because of the low complexity of the system and the fact that only one concept was kept for hose routing, in combination with the fact that two different solutions would not be implemented to solve the same problem, the number of possible solutions was decreased to seven. It was decided that the original hose routing would be used in each set of solutions. Meanwhile the original hose should be used together with the new concepts for removing the pressure difference, while the new concepts for removing water movement would be combined with the original drain plug.

The Pugh screening was performed in two iterations, first with the current solution as datum and secondly with the “soft non-return valve” concept which got the most plusses during the first iteration. The scoring was performed twice in order to ensure that the results converged.

Only one concept was decided to be eliminated after the Pugh screening, this was the “hose with rubber bulb”. The solution received the lowest score in both of the iterations and was therefore removed. The Pugh matrix also showed that the concept “non-return valve which closes when pressurised” received bad values. This concept was however decided to be investigated further since more information was required before it could be discarded.

When evaluating the Pugh matrix to investigate if one or more concepts could be modified, where they received bad values, it was concluded that the low complexity of the system made it hard or unfeasible to combine or change the concepts for the better at this point.

5.2 Second concept loop

After the first concept loop the remaining concepts needed to be developed further and preferably, be described at an equally detailed level. The remaining concepts are illustrated in a second morphological matrix in Appendix A30. The concepts that were possibility to test without the construction of expensive prototypes were tested during this phase. The concepts which are discussed in this chapter (except the ones shown not to work during testing) are further evaluated in the Kesselring concepts scoring matrix.

Two of the concepts (concept three in 5.2.4 and concept two in 5.2.5) are in fact outside of the delimitations stated in the introduction chapter of this report (see chapter 1.4). The reason for this is to show a wider solution spectrum with ideas that can potentially be used in future projects.

5.2.1 Hose inner structure with smaller canals

As mentioned, the idea with the new inner hose structure is to split up the water in different canals and stop it from climbing upwards within the hose. The problem itself is not that the water is climbing in the hose, it is rather the sound it makes when the accumulated water bubbles burst. The idea is a hose with small canals along the inside of the hose, which would divide the water into smaller portions of accumulated water. A simplified illustration of the inner structure of the hose is shown in Figure 5.2.

Figure 5.2 – Hose inner structure with smaller canals

The concept itself is realisable and could be rather easily manufactured through extrusion. The reliability is still good but it could be discussed if dirt could get stuck easier inside the hose. When considering cost the profile is simple but will most probably require a new tool. The hose itself will also consume a little more material for manufacturing because of its new inner shape. Economically this means that the material cost will increase as well as the initial cost of new tooling will increase, but the overall price increase is small.

During discussion with one of the polymer specialists at VCC it was concluded that this concept would probably not remove the sound phenomenon. This is because the latter is not due to capillary forces but rather caused by the air flow which forces the water to move inside the hose. This would imply that the sound phenomenon does not mainly depend on the inner structure of the hose, which would in turn mean that the concept will most likely will not work. However, since the following concept consists of a similar solution, which could quite easily be tested, it was decided that the outcome of that test would determine if effort should be put on testing a hose with small inner canals as well.

5.2.2 Ribbed/bellowed inner structure of hose

Both these hose concepts are based on the same principle, to change the inner structure of the hose and in this way making it harder for water to move upwards through it. The drips of water would be separated into smaller ones and in this way make it harder or even impossible for the gurgling sound to occur.

The concept would be relatively cheap as these types of hoses are used in a wide range of other applications. Further, this type of solution is very robust and functionality will not degrade as the product ages. If a change in hose shape would be sufficient to solve the problem it is a solution that could be implemented on virtually all of VCC´s car models. The hoses could be used with the existing components of the drainage system, making the solution easy to implement. An illustration of the bellowed hose concept is shown in Figure 5.3.

There is a risk of a marginally reduced drainage capacity as some water can be kept stagnated in the hoses due to the altered shape. It is also possible that small dirt particles can get stuck on the profile edges within the hose. This could lead to a build-up of more dirt and in the long run even clogging of the drain hoses.

Figure 5.3 - Illustration of a bellowed hose

A bellowed hose with 9 mm inner diameter was purchased and used to test the concept. The hose was mounted in a S60 and taken for a test drive. There was no problem to provoke the sound phenomenon to occur while driving and because of this it could be concluded that the concept does not work. The sound phenomenon was changed with regard to noise frequency but nonetheless the problem remained.

Since the bellowed and ribbed hose concept failed the concept with smaller inner canals was decided to be eliminated as well since the main idea behind the concepts is the same.

5.2.3 Hose with inner spiral

The technique of using a spiral fin within the drain hose is provided by a German company producing plastic components for the automotive industry. According to the manufacturer the technology is effective against road- and wind noise, without reducing drainage capacity. The effect of using a spiral within the hose works by a combination of reflection and absorption of noise (Kunststoffwerk Voerde, Hueck & Schade GmbH & Co. KG, 2000). This type of hose would most certainly be a bit more expensive than a traditional one but the noise reduction, if proven to be working well, could justify the increased cost. Figure 5.4 shows what the interior of the hose looks like. This type of hose can also be equipped with exterior fins that reduce squeak and rattle noise from the drain hose. These fins are shown to the right in Figure 5.4.

Unfortunately the technique is patented and therefore, would have to be bought from this manufacturer. However, it was regarded as interesting to test this type of hose to see if it eliminates the gurgling noise.

Some sample hoses of this type were ordered from the manufacturer and mounted in an S60 for testing of the concept. It was however observed that the sound phenomenon was not removed by the hose, instead it seemed like it was harder to drain the water. The hose is also available without the inner spiral and only the outer fins. This hose could be interesting for other projects since it could mean that the number of clips to fasten the hose could potentially be reduced.

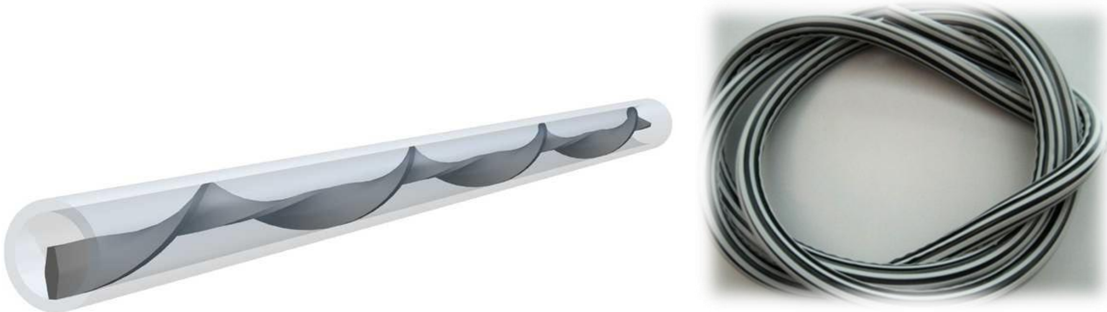


Figure 5.4 – Illustration of drain hose with inner spiral (Kunststoffwerk Voerde, Hueck & Schade GmbH & Co. KG, 2000). Left – Illustration of the inner spiral. Right – Photo of the hose, note the grey fins.

5.2.4 Soft non-return valve

The principle of a non-return valve concept is to remove the airflow through the hose and thereby stop the water from moving upwards within it. A soft non-return valve is designed as one part, where the soft rubber material enables the flexible lid to open and close itself when adequate force is applied. The concept can be realised either at the water inlet or outlet of the sunroof drainage system. The idea is that the lid in normal state should be more or less closed and when the pressure difference occurs within the drainage system it should be entirely closed, to stop any air from passing through.

Pros with the soft non-return valve are that it has been proven to eliminate the sound phenomenon during tests with the so called Y0 drain plug (see chapter 4.1) merged with the existing drain plug. Potential problems with the soft non-return valve are that the lid might freeze and disable drainage capability in cold climates. There is also a risk in warm climates with high humidity that microorganisms starts to grow in the opening. These could in worst case grow in such a way that the lid will be disabled from opening, leading to flooding and water leakage into the interior of the car.

The first concept is when the soft non-return valve is integrated within the end of the drain plug. The lid which would serve as non-return valve would be much like the Y0 drain plug, see

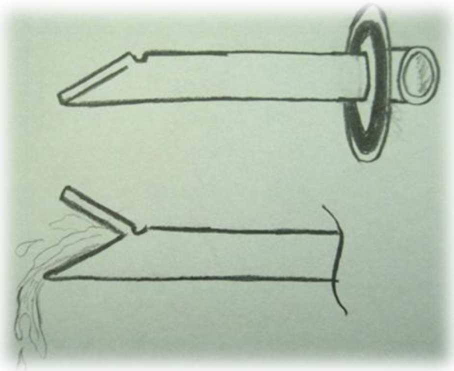


Figure 5.5 for an illustration of a soft non-return valve integrated with the drain plug. In this case the soft non-return valve would be facing upwards, to make the lid more or less closed in its standard state. This design requires two different drain plugs, separate ones for the left and the right hand side of the car, in order to enable the lid to face upwards on both sides.

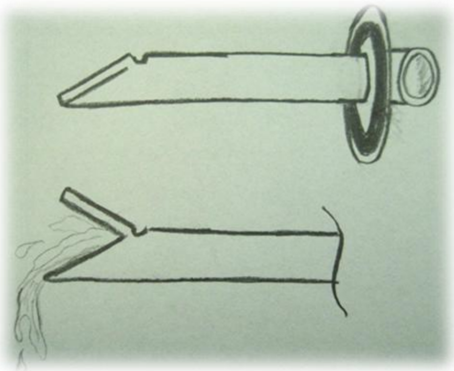


Figure 5.5 – Raw sketch of drain plug tip with soft non-return valve

The second concept is the same as the first concept with the soft non-return valve integrated with the drain plug, the difference regards which side the soft lid is facing. In this case it is facing the side instead of upwards. By placing the lid on the side the drain plug should have a small opening in standard position and thereby more or less eliminate the risk of freezing or microorganisms from clogging the plug. This design only needs one drain plug since the lid will face the side in both mounted positions (right and left hand side of car).

The third concept is when the soft non-return valve is integrated in the sunroof frame. This would probably be more complex and expensive to achieve, since this would affect more parts. The soft lid should then be placed in the end of the pipe connected to the drain hose. The lid would more or less be closed in the standard position and be tightly closed while driving as an effect of the pressure difference between the upper and the lower end of the drain hose. Figure 5.6 illustrates the concept with a soft non-return valve integrated in the sunroof frame.

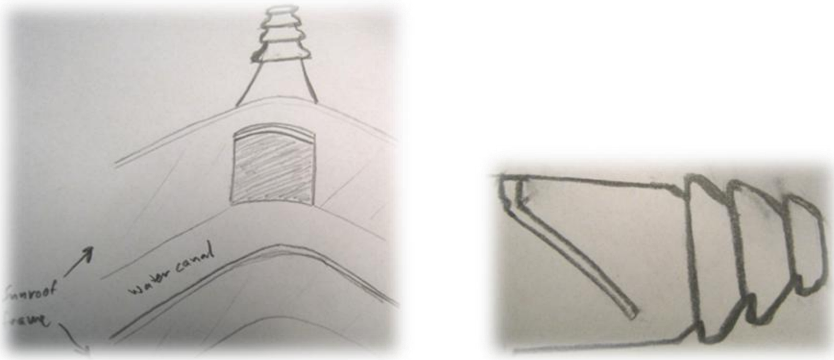


Figure 5.6 – Raw sketch of soft non-return valve integrated in the sunroof frame. Left: Front view. Right: Side view

5.2.5 Hard non-return valve

This concept uses the same method as the previously mentioned, where the solution takes advantage of the pressure difference within the drain hose while driving. A hatch or lid which closes off the drain hose has some risks connected to it. During wintertime there is always a risk that the lid freezes shut. This increases the risk with flooding of the drainage system. The robustness of having moving parts could be discussed as well. The component is supposed to last and function for a long time and failure can lead to either the recurrence of the unwanted sound phenomenon or water entering the interior.

The first concept would be to add a hard plastic component to the original drain plug which would work as a lid. This would require manufacturing and implementation of one more component to the system and hence, add some assembly time. On the other hand this would remove the unwanted sound phenomenon and the extra cost and assembly time could thereby be justified. Figure 5.7 illustrates the idea of a hard non-return valve integrated in the drain plug.

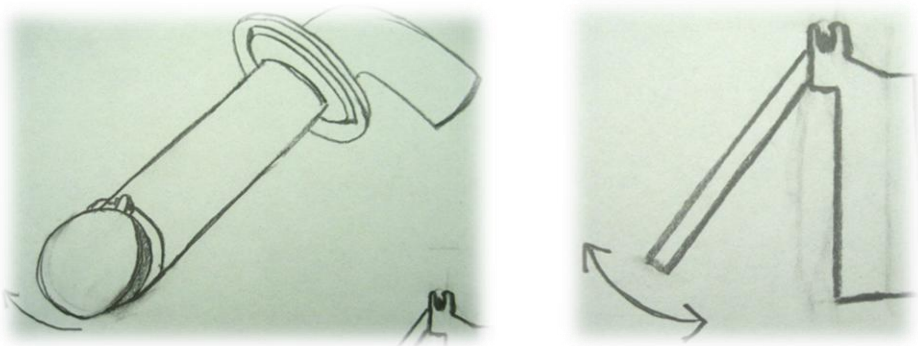
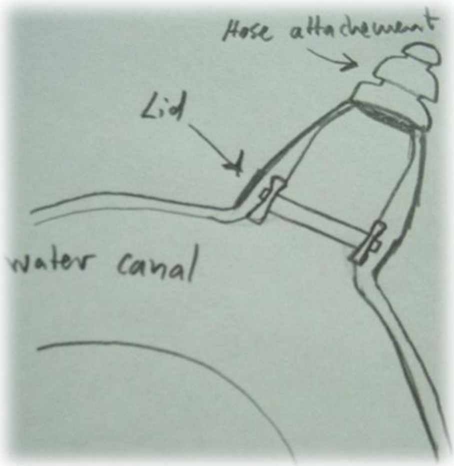


Figure 5.7 – Raw sketch of drain plug with a hard non-return valve with hinges. Left: whole drain plug with hard non-return valve. Right: Side view of hard non-return valve with hinges.

The second concept would be to add the hard non-return valve in the frame of the sunroof. Placed on the frame is a small lid, which will be a separate component, attached by a simple geometric hinge. The lid would be closed when no water is pouring through the seal system of the sunroof and it will open itself to drain water by the force of the water, see Figure 5.8 for a raw sketch of the idea.



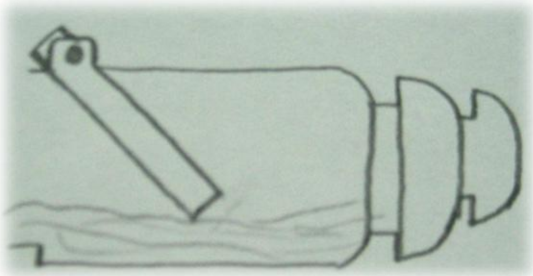


Figure 5.8 - Raw sketch of the hard non-return valve integrated in the sunroof frame. Left: Overview from the top. Right: side view of the hard non-return valve

5.2.6 Non-return valve which closes when pressurised

The idea with the non-return valve which closes when pressurised is to disable clogging of dirt, microorganisms and icing. The general concept of having a non-return valve that closes when the pressure difference between the top- and bottom end of the drain hose is large enough can be further broken down into three realisation principles. More ideas for similar concepts can most certainly be derived but when feasibility is to be considered the number decreases.

The first concept is to use a non-return valve in a softer rubber material. This should be flexible enough to shut the drain hose when pressure increases (as when increasing speed to about 100 km/h) and still stiff enough to hold the lid open in the valve´s static condition, see Figure 5.9 for a raw illustration of the drain plug. The appearance of this type of solution can vary to some extent. For instance, the valve can be located either at the bottom- or at the top end of the drain hose. Further, the opening and geometry of the non-return valve can have different shapes according to what is considered to be optimal in terms of functionality and solution robustness. This will be investigated at a later stage in the development process if the concept is taken into detailed development.

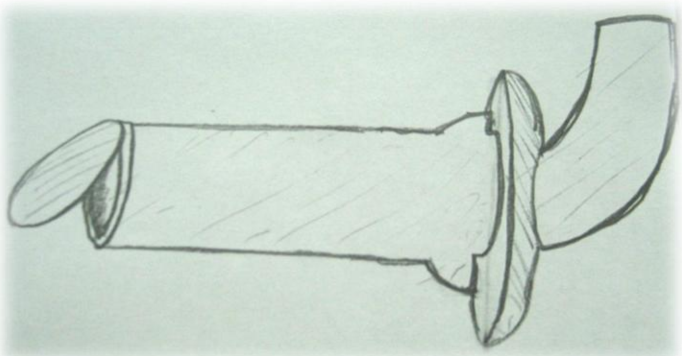


Figure 5.9 - Raw sketch of the non-return valve which closes when pressurised, integrated in drain plug

The second concept utilizes a chamber within the drain hose in which a ball is located. The ball should be in a low-density material and be able to move within the chamber. When the pressure difference in the hose is large enough the ball will move upwards and close the hose and hence, stop the air-flow through it, see Figure 5.10 for a raw sketch of the principle. This would make it impossible for the water to wander upwards within the tube and thereby solve the problem with the unwanted sound phenomenon.

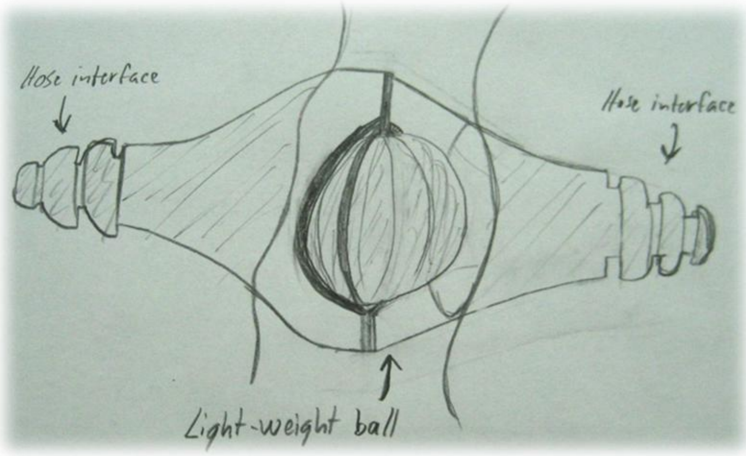


Figure 5.10 - Raw sketch of non-return valve which utilises a ball to close off the air flow when pressurised

The third concept principle is to have a small hatch within the tube which is attached to a spring. The pressure difference on either side of the hatch would at a certain point be large enough to draw or push the spring and hence, make the hatch close off the airflow through the hose, see Figure 5.11 for a raw sketch of the concept.

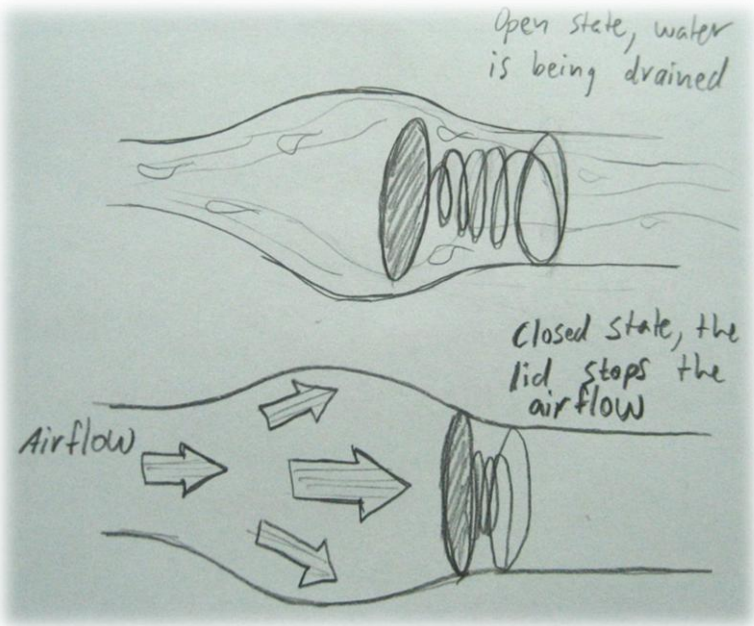


Figure 5.11 - Raw sketch of a non-return valve with lid attatched to spring that closes when pressurised

5.2.7 Kesselring concept scoring

In order to make a judgment on which of the remaining concepts that should be kept for detailed development the Kesselring concept scoring matrix was applied. The same criteria used in the Pugh screening matrix was once more the basis for the judgment of concepts. Within the Kesselring matrix the different weights on the criteria was also used to calculate the concept scores. The Kesselring matrix and its result can be found in Appendix A32.

From the Kesselring matrix it was shown that the concepts with soft non-return valves received the best scoring. Soft non-return valve with lid facing the side was judged as the best solution, closely followed by the one with lid facing upwards. It was decided that these two concepts should be realised as prototypes and further tested and evaluated.

5.3 Final concept loop

The two remaining concepts kept for further investigation build upon the same principle and are therefore more or less the same with respect to appearance and functionality. The final assessment of the concepts is described in this part of the report.

5.3.1 Deep analysis of remaining concepts

The two remaining concepts both use a soft non-return valve to disable the unwanted sound phenomenon. The phenomenon is eliminated since the soft lid, which is working as a non-return valve, is closed during driving when no water is passing it and thereby prevents the air from flowing up through the drain hose.

Both drain plugs are exactly the same except from their lower part where the soft lid is situated. The first solution has the lid facing upwards while the second has the lid facing the side. The idea for both was tested at Hällered proving ground during the ad-hoc tests performed there (see chapter 4.6). During these tests the Y0 drain plug was mounted on the end part of the original drain plug and this eliminated the sound phenomenon.

The new design of the drain plug concepts uses the major parts of both the original and the Y0 drain plugs. The upper part of the original drain plug has been used as connection to the drain hose and pass-through of the car body, since these parts have worked without flaws. The lower part of the drain plug has been widened in comparison to the original one in order to maximize the drainage capacity. The new inner diameter is now the same throughout the whole plug instead of narrowed towards the exit hole. The non-return valve from the Y0 drainage has then been used in the new concept with some minor adjustments. The diameter has been widened, thereby making the exit hole larger; the slit where the lid is placed is tilted to enlarge the exit hole even more. The thought behind the modifications is that the risk of dirt clogging the system will be minimised as well as the risk of ice to freeze the plug shut. Further the enlarged end hole will make it harder for microorganisms to grow as an increased water flow will make it more difficult for them to attach and block the opening.

The first solution, with the lid facing upwards, takes advantage of gravity to close off the drain hose while driving. On the downside this solution requires two different plugs, one for each side of the car. This is since the lid would otherwise be placed downwards on one of the sides. In worst case this would require two different tools or at least a modification which would not be needed for the solution with the lid facing the side. The latter only requires one variant since this could be used on both the left and the right side without compromising the position of the lid.

The material used in the drain plugs today was studied in order to investigate what material properties that was of importance for its functionality. The original drain plug is made of TPE Shore 75 A while the Y0 drain plug is made of EPDM Shore 60 A. The original drain plug is hard in order to ease assembly and maximise the chance for an operator to recognise when the part has not been correctly assembled. The idea is that the harder material should make the drain plug harder to bend in between the two sheets of metal in which it is mounted, without negatively affecting the fitting to the car body. The Y0 drain plug on the other hand is soft in order to enable the lid to open and close when water is pushing on it. With this in mind the choice of material is to be made during the testing procedure of the actual drain plug. The decision needs to be taken together with the manufacturing engineers who decide if a part could be implemented in manufacturing or not.

As in almost every construction there are some existing compromises or trade-offs that need to be taken into consideration. These compromises are more or less the same as for the original drain plug. The main parameters of the plug are drainage capacity, sound isolation, size, resistance to microorganism growth and freezing. The drainage capacity requires a large inner diameter of the drain hose and plug but because of packaging aspects the size is very limited. The size of the drain plug and its opening also affects the risk of icing and growth of microorganisms. A large drain plug will minimise the risk of microorganisms to clog the plug and also blocking by ice. At the same time, if the lid is too big it might be too heavy for the underpressure to close it tight, especially if the lid is facing the side. In Figure 5.12 the two final concepts are illustrated as CAD models.

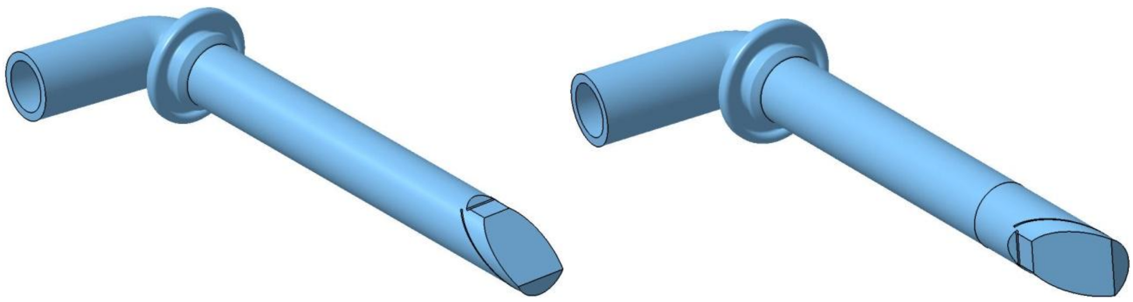


Figure 5.12 - CAD models of the two final concepts: drain plug with soft non-return valve. Left: lid facing upwards. Right: lid facing the side

5.3.2 Construction of physical prototypes

In order to assess the functionality of the final concepts creation of physical prototypes for functionality testing was carried out. The prototypes were first created as CAD models in CATIA V5. These models had to be adopted for mould creation and for this purpose four different models were needed; the outer geometry of the drain plug, two inner core parts and one back valve. The latter could then be attached in two different ways depending on if the lid was to be mounted upwards or to the side. The non-return valve FFF core used to make the silicone tool for the non-return valve is shown in Figure 5.13.

Figure 5.13 - Picture showing FFF core of the drain plug non-return valve

The different parts were first free-form fabricated in order to construct the tool for the drain plugs. The FFF outer geometry of the drain plug was placed in a silicone bath which created a mould for the prototypes. The silicone mould then was split in two parts in order to ease demounting of the finished parts. When making the drain plugs the free-form fabricated inner cores were placed inside of the mould and the tool was then filled with material during a vacuum casting process. The silicone tool and the inner cores can be seen in Figure 5.14.

Figure 5.14 - Picture of the silicone tool. Left: Main part of the drain plug, split in two parts, with the two inner core parts mounted. Right: Tool for the non-return valve

The prototypes were created through vacuum casting at the Concept centre, responsible for the prototyping abilities at VCC. The prototypes were moulded in two different materials; Alchemix VC 332 A/B with 60 - 65 Shore A and MCP Vacuum Casting Resin with hardness Shore 70 A and Shore 80 A. The materials were chosen to resemble the ones used in the Y0 drain plug and the original drain plug. Two variants of prototypes can be seen in Figure 5.15. In total six drain plugs were produced, two in each material with the lid facing upwards and on the side respectively. In order to ease assembly of the non-return valve, reference marks were placed on the drain plug and on the non-return valve, showing how the two parts should be glued together if the lid was to be positioned upwards or to the side.

Figure 5.15 - Picture of two different drain plug prototypes. The upper one is with lid facing upwards while the lower one has its lid facing the side.

5.4 Environmental aspects

All development work carried out in today's modern society needs to have a clear focus on environmental aspects. This is especially important within the automotive industry, as a clear trend towards environmental friendliness can be seen in this business sector. Most car manufacturers want to show their customers that their products are the most environmentally friendly. Governmental policies also strive towards tougher and tougher regulations on carbon dioxide emissions (European Parliament, Council, 2009).

The need to replace fossil fuels in the automotive industry has led to the development of hybrid- and electrical vehicles. Almost all major car manufacturers in the world have a strong focus on this. Fuel consumption is another aspect that a lot of development effort has been put into in order to make the cars more energy efficient (Ohnsman, 2010). The focus is not solely on the engines but on the entire vehicle. By striving to lower the mass of all components in the car and working with aerodynamics, engineers have made it possible to reduce fuel consumption and carbon dioxide emissions to a great extent.

During this entire project environmental aspects have always been considered when comparing different solutions, choosing between materials, manufacturing methods and so forth. Naturally there are times when the highest priority has been on other properties than environmental friendliness, nonetheless the strive is to always make decisions that has the least impact on the environment without sacrificing functionality.

When reviewing the components that have been developed during this project the highest impact on the environment can be found in the choice and amount of material used as well as in the manufacturing method applied. Since the components are relatively simple and straightforward this is more or less the only parameters that can be altered in order to reduce the eco-impact.

6. Control - Verification of new concepts

The control phase is the final step in the DMAIC methodology. This phase includes testing and verification of the new concepts. After the verification the final concept is chosen and presented and in order to ease implementation of this concept, recommendations for additional verification work concludes this chapter.

The new concepts need to be verified in order to ensure that they fulfil the different needs and requirements on the product. This includes the ones stated by Volvo Cars when developing the original drain plug, as well as the ones identified during the course of this project.

6.1 Test of final prototypes

The prototypes of the two drain plug variants need to be assessed with regard to their intended functionality. This verification is carried out in a series of different tests. Several of the test procedures are standardised within VCC and will be needed to be performed under the supervision of the respective attribute leaders. Some of the tests are either too long or need to be done on the actual product, making them unfeasible for this master's thesis project. Those test procedures will be left as recommendations for further verification work.

6.1.1 Functional tests

First of all it was essential to test the new drain plugs with respect to their ability to solve the problem with the unwanted sound phenomenon. This was done by mounting the prototype drain plugs in a test vehicle, applying water to the drainage system and taking the car out for a test drive. If the sound phenomenon cannot be provoked to occur during a set of tries when test driving, the new drain plug can be considered to be working. A final verification was carried out with the aid of an engineer from the solidity department who made a final judgment on the ability to solve the sound phenomenon at the TT-track.

Five different prototypes were tested; two versions of end opening positioning and three different materials. The prototype with medium hard material and lid mounted to the side was not tested due to other prioritisation because of time constraints. A Volvo S60 was used as test vehicle and the results of the tests are summarised in Table 6.1.

Table 6.1 - Test results from functional testing of physical drain plug prototypes

End opening positioning	Material	Result – Solves sound problem?
Top mounted lid	ALCHEMIX VC 332, Shore 60 A	Yes
Top mounted lid	MCP Vacuum casting resin 7170, Shore 70 A	Yes
Top mounted lid	MCP Vacuum casting resin 7180, Shore 80 A	No
Side mounted lid	ALCHEMIX VC 332, Shore 60 A	Yes
Side mounted lid	MCP Vacuum casting resin 7170, Shore 70 A	Not tested
Side mounted lid	MCP Vacuum casting resin 7180, Shore 80 A	No

The functional testing requires some explanations regarding the procedure and results. Water was poured into the drainage system at least twice during the test run. First it was applied at standstill with the car standing on a planar surface. The car was then driven at speeds between 90-120 km/h with tilted sunroof in order to provoke the sound phenomenon to occur. If it did not occur after this first test water was added to the system while driving. All prototypes passed the first test, although after adding water while driving the gurgling sound commenced on two of the prototypes. The failing prototypes were made in the hardest material with Shore 80 A. They might have failed since the harder material makes the lid less flexible and less prone to close tightly. When water was added, in combination with the air flow originating from the pressure differences between the top- and bottom end of the hose, the lid might not have been able to close tightly again.

Because of this it is recommended that the non-return valve is made of a material softer than Shore 80 A.

6.1.2 Testing of drainage capacity

The drain hoses with drain plugs have a requirement on drainage capacity of two litres per minute. The new drain plug designs would in theory not have lower capacity than the original drain plug but this had to be verified.

After discussions with the master's thesis supervisor at VCC it was decided that the test rig used for the cold climate tests (see chapter 4.7) could be used for this test as well. The required accuracy of the tests was quite low as it only needed to be verified if the drain plug prototype fulfilled the requirement or not. The original drain plug was used as reference.

The drain plug to be tested was attached to the test rig. A graduated cylinder was filled with two litres of water. The water was then poured at maximum pace into the funnel and the time it took to empty the cylinder was measured. The experiment description can be seen in Appendix XLIII. Each of the tested drain plugs had the same or shorter drainage time than the original drain plug. During the tests it was shown that the new concepts could drain up to 4 litres per minute.

6.1.3 Cold climate tests of prototypes

The functionality of the new drain plugs in cold climates and their resistance to ice clogging was important to test. This was something that could relatively easy be verified through tests in the climate chamber, which was used at an earlier stage when conducting tests on different benchmarked products (see chapter 4.7). The same test procedure as before was applied and it can be studied in its full in Appendix A23.

The climate tests showed that the result from the different prototypes did not vary to a large extent between the different materials or between placements of the lid. None of the plugs froze entirely, although some tests ended up with semi frozen drain plugs. The semi frozen drain plugs did leak water from the beginning when water was applied and would soon open up entirely to enable full drainage capacity. This result was the same as for the drain plug used today, which also semi froze during some of the tests.

6.1.4 Manufacturing engineering

In order to get a new component accepted for assembly the manufacturing engineers must approve it. Their task is to test and evaluate new parts for assembly and suggest adjustments to them (if needed in order to be accepted). When a part has been accepted a description for how to assemble it is prepared and it is decided when it should be implemented in production.

In order to enable ease of assembly the Poka yoke idea has been used. Poke yoke is a mistake-proofing methodology the idea of which is to avoid unnecessary errors by making it impossible or at least make it very hard to do wrong. The idea is also that if something goes wrong it should be easy to identify (Brue & Launsby, 2003). It was investigated at an earlier stage if the original drain plug could be modified to only be possible to mount in one position and thereby prevent it from being fitted in different angles. The idea was to use a key connection where the drain plug had an extra feature in its interface to the car body, making it possible to mount in one way only. The idea was however discarded since the drain plug could not be manufactured with the extra feature required.

In order to ease assembly of the drain plug and enable the assembly worker to detect errors regarding mounting through the second sheet of metal, a stiffer material is preferred. The two sheets of metal can be seen in Figure 6.1 which is a picture from a DMU of a mounted drain plug. The stiffer material could disable the drain plug from bending between the metal sheets, if the plug should miss the second outlet hole, thus alarming the assembly worker that something is wrong.

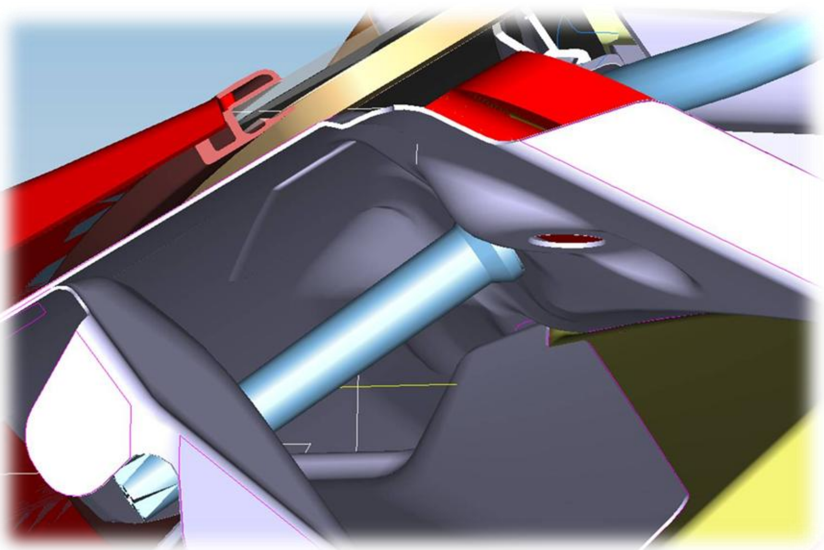


Figure 6.1 - Digital mock-up of mounted drain plug, note the two different metal sheets

To ensure that the water, which passes along the hose into the drain plug, enters the plug and does not leak into the car interior the hose is mounted inside the drain plug.

The responsible manufacturing engineer within this area working with running changes (changes affecting cars already in production) was contacted regarding the drain plug prototypes. The different prototypes were assembled in an empty car body of a Volvo S60 to investigate their ease of assembly. It was decided that the overall design could be accepted for assembly if the material would be harder than that of the prototype with hardness Shore 60 A.

The soft material made it too difficult for the assembly worker to notice if the detail was mounted in the wrong way or not.

6.1.5 Time, technique and cost

Volvo Car Corporation uses Time, Technique and Cost as three aspects to use for evaluation of new concepts before implementation. The information within each area depends on the type of concept and in which phase of development it is in. Time, technique and cost are often used to compare an old concept against a new one or to choose between two or more alternatives. In this case both the old and the two new concepts were evaluated.

Time

Time is measured in many areas and can be used from the first idea of a new concept until it is put into production or even until the end of the product life. The latter will not be measured since it is the same for both the new concepts.

The time until the new drain plug variants could be implemented in production is also more or less the same, since the difference between them is small. The lead time from placing the order to delivery of first detail is interesting as well as when the approval of the production of the drain plug can be signed. The soft non-return valve with lid facing upwards will probably consume more time to produce since it would need two different tools for the right- and the left hand side of the drainage system.

The current supplier of the drain plug has been contacted and discussions on when a new solution can be in production have been initiated. The answer to the questions had however not yet been answered by the supplier at the time of writing of this report. VCC has a set of implementation windows spread throughout the year when changes to products in production are carried out. It is during one of these windows that the new drain plug will be implemented if the new solution is approved for production.

Technique

The technique aspect ranges from the problem at hand through design to which tests that are needed for validation. The problem at hand has to do with an airflow which forces stagnated water inside of the drain hose to climb and accumulated water droplets to burst, which leads to an unwanted sound phenomenon. The two new concepts will solve the problem trough a non-return valve which will disable the airflow through the hose, the water from climbing and hence, the sound phenomenon. However the non-return valve could affect other properties of the system negatively. The drainage capacity could be reduced and the risk of dirt, ice and microorganisms to clog the system could be increased. In order to avoid the stated possible problems some further design changes have been made.

Design wise the new concepts are a combination of the major parts of two drain plugs. As mentioned the upper part of the original drain plug has been reused in the new concept and the non-return valve from the Y0 drain plug. Some changes have been made to the plug to improve its functionality. Enlargement of the end parts inner- and outer diameters in order to reduce risk of dirt etcetera to clog the pipe has been implemented. The pipe has also been elongated to make it impossible for the lid to get stuck in open position during assembly.

Assembly is also one area that might be affected negatively because of the design changes. This is due to the widening of the plug, making it harder to fit in the holes in the car body.

Cost

Cost wise the original drain plugs can be compared to the new design to assess how cost efficient a change of component would be. The tooling, material and part price can be looked into, as well as the development cost and manufacturing of prototypes and validation tests.

Material costs would increase slightly with the new drain plug design proposals. This is since the non-return valve will require some additional material as compared to the original drain plug. The cost of new tools is however the large expenditure. If the new drain plug can be used in several of the upcoming car models the tool costs can be shared between larger volumes of components and hence, the cost per drain plug will be less.

The supplier of the current drain plug has assessed the production price of the new design in order for a comparison to be made. The difference in cost was approximated to increase by 0,61 SEK / component. The cost for the production of a new tool will be approximately the same as the tool cost for the original design.

6.2 Final concept

After the series of verification tests, an assessment of which concept that should be presented as the final solution proposal was carried out. The tests had shown minor differences between the two concepts. However, the robustness issue was discussed with one of the senior material experts at the R&D department. Having the lid of the non-return valve facing the side could over time lead to problems, as gravity could not be used to close the lid. It was not certain that the functionality would last over time as the material will age and get worn. This would not affect the non-return valve facing upwards to the same extent since the gravity would work with it instead of against. With this in mind the final concept was chosen to be soft non-return valve with lid facing upwards, see Figure 6.2.

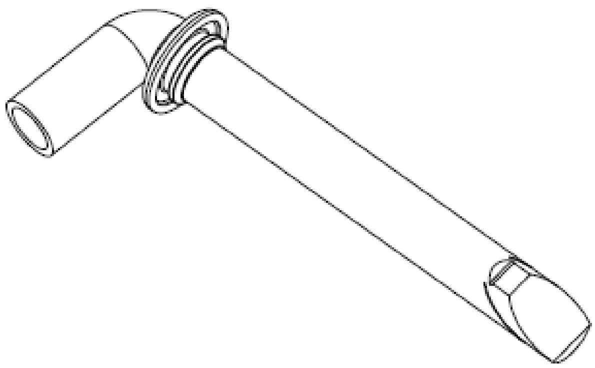


Figure 6.2 - 3D drawing of the final concept, soft non-return valve with lid facing upwards

The drawback with the solution having a lid facing upwards is that two versions of the component are required, one for each side of the car. This could potentially lead to problems in the manufacturing process as the assembly workers could mount one of the components on the wrong side, making the lid face downwards and thereby disabling its functionality. This risk could be minimised by for instance marking the drain plugs with the word "Up" on the corresponding side. Having two versions of the component might also lead to an increase in tool costs and logistics. Nonetheless, functionality had to be prioritised and because of this it was decided that the drain plug with lid facing upwards should be presented as the final solution.

A drawing of the drain plug from the CAD model was created in CATIA V5. This could be used to present the component to the supplier and get feedback on what needs to be redesigned in order to ease the manufacturing process. For instance it is known that the lower part of the drain plug (pipe including the back-valve) needs to be conical. The conical form is needed due to the manufacturing process and in order to make it detachable from the manufacturing tool. Some of the tolerances need to be assessed with respect to manufacturability and are therefore left out in the drawing. The initial drawing is displayed in Appendix A34.

6.3 Additional verification

It must be taken into consideration that the verifications of the new drain plug design were carried out on prototypes. This means that the final drain plug might be changed and modified in ways that might affect the test results. The material in the prototypes is not the same as the material that will be used in the actual detail. Therefore it is important to study the tests already made and then consider if these need to be repeated or not.

The TR for the drainage system states a series of requirements that the system needs to fulfil and also how these are supposed to be verified. Due to time constraints, availability of material and test facilities some of the tests on the drain plug could not be carried out during the timeframe of this master's thesis project.

Some tests and verifications on the final detail could also be skipped if the material will be the same as in the original drain plug. These tests and verifications regard material properties like burning rate, ageing properties and so forth. With these aspects in mind it could be said that the TR needs to be studied in order to investigate which tests that need to be performed on the drain plug.

7. Discussion and conclusions

The discussion chapter focuses on what could be considered in the future regarding the sunroof drainage systems in Volvo´s car models. The DMAIC Methodology used during the project is also discussed regarding its pros and cons in this type of development project.

The development of a car is very complex and requires cooperation between many different technology disciplines. This is something that has been seen during the course this project, even though the drainage system is a relatively simple system there have been struggles between different property areas.

7.1 What could be done in future car models

During the course of this project a set of lessons learned has been compiled. It has been recognised that quite often solutions that have worked in previous projects are reused (if a whole component or concept is reused it is called carry-over). This is also something that has been taken advantage of during this development project. It is natural to think that a solution functioning as intended in one product will function just as well in another. During this project it has been shown that this is not always the case. A slight change in the surrounding environment of a system can be enough for problems to arise.

In this project the inclination of the hose was the large contributor to the emergence of problems. The Volvo XC60 which uses the same components of drain hose and drain plug has shown to be working properly, although when the same components were fitted in the V- and S60 there were problems with the unwanted sound phenomenon. The main difference between the car models were the drain hose routing. It is stated in the technical regulation that the hose routing should not have an inclinations below 7°. This recommendation was however not followed for reasons concerning the surrounding space of the system, affecting the possible routing paths. This is often the case when developing complex products as trade-offs have to be made on contradicting requirements.

What should be kept in mind for future projects at VCC is that sufficient hose inclination, to make sure that no water can be kept stagnating in the system, is of great importance if one wishes to avoid problems with unwanted sounds. What has been shown during this master's thesis project could also be used to stress the importance of this in situations where discussions are carried out on hose routing. The fact could also be used to emphasise the need of relocation of the exit area for the drain plug. Change of exit area for the drain plug could minimise the pressure difference between the upper and lower part of the drainage system which is also a part of the problem. It would be interesting to reinvestigate older solutions as well as new areas were the water could exit the drainage system.

A recommended test procedure during development of new car models with sunroofs that can be opened would be to test drive these at the TT-track, with tilted sunroof after adding of water. This is in order to ensure that this problem does not occur again and if it does, it could be detected early to allow the problem to be solved before production start.

One of the other major problems with the drain plugs used today has been clogging of vicious microorganisms. Since there is a risk of this problem to still emerge it could be interesting to have a discussion with suppliers regarding materials with some kind of resistance against these.

7.2 Reflection on the DMAIC methodology

During this master's thesis project, the DMAIC methodology taken from the Six Sigma business management strategy has been applied. This methodology offers a structured process of conducting improvement work and it has shown to function very well for this type of application. However, the methodology is primarily aimed at improving processes and most of the literature about it describes this type of work. Despite this fact the methods chosen from the Six Sigma strategy have proven to be very applicable to product development work as well. The methods have sometimes needed a bit of adaptation to suit their intended purposes, however this is also the case with several of the product development methods and tools available.

If one looks at the adaptability and strictness of the methodology, it is relatively non-strict and offers the possibility of adapting it for a projects specific need. It also offers the possibility to work iteratively within the different phases, which is very useful when conducting product development work.

The usefulness of the DMAIC methodology in new product development projects is a bit more questionable. It would be possible to use several of the methods in this type of projects as well but in this case there are other better, more specialised methods to apply. An example of this could be the Design for Six Sigma (DFSS) methodology.

7.3 Reflection on the use of decision matrices

During the improvement phase of this project a set of decision matrices were used (Elimination matrix, Pugh matrix and Kesselring matrix). These are very useful and straightforward to apply when evaluation different concept proposals and screening among these. However, there is a major drawback connected to the use of these and that is their subjectivity. The persons using the matrices strongly affect the outcome and which concepts that are kept for further development. This means that it is possible to get different results depending on the skill and knowledge of the people using them.

In this project particularly it is possible that the outcome could have been different if one or several of VCC´s own engineers had been involved in the concept screening process. It is possible that they would have seen more potential in some of the concept proposals in comparison to what the authors of this report saw and hence, the winning concept might have differed.

7.4 Recommendations

In order to finish the development of the new drain plug and be able to implement it in assembly some additional work needs to be carried out. This remaining work regards the things that this master's thesis project did not have time to consider or look into. These recommendations are mainly focused on optimisation of the design and the industrialisation of the new component. It is recommended that the following tasks are looked into in order to ensure good functionality of the new drain plug:

- The design needs to be adapted to manufacturing. Discussions need to be carried out with the supplier to identify which changes that need to be made in order to make the component possible to manufacture.
- An assessment regarding the resistance to poor assembly of the new components is needed and how the two different versions for the left- and the right hand side of the drain plug could be separated. This is in order to minimise the risk of them being mounted incorrectly and especially at the wrong side of the vehicle.
- A detailed cost assessment needs to be carried out in order to pass judgment on the feasibility of the new design. An initial contact has been taken with the supplier but no answer regarding tool costs, time to production and approximate cost per component had been received when this report was finalised.
- The material and especially the hardness of the material are important for the functionality of the new drain plug. It is suggested that a certain type of TPE should be used in order to have a quality assured material as different types of TPE have different properties. The brand of TPE suggested by the material expert at the Exterior department is called TPV and of the brand Santoprene™.
- Additional verification of prototypes manufactured in the material intended for use in production need to be carried out. Further, the recommended hardness of the material is 70 Shore A. It needs to be confirmed that this hardness is optimal for the non-return valve functionality when using the final material as well.
- The ability of the new drain plug to resist growth of microorganisms in warm and moist climates needs to be investigated further. No test method for this exists at the moment and since there have been problems with earlier drain plug designs in this matter it is important to make an assessment on how well the new drain plug will cope with the problem.

7.5 Conclusions

The objective of this master's thesis project was to investigate the cause of a sound phenomenon and how the problem could be eliminated. The problem was investigated through the aid of the DMAIC methodology which structured the work and provided good tools for this type of improvement project. The methodology was useful for getting a broad understanding of the system and problem at hand, as well as for finding a solution to solve it.

The goal of the project was divided into one primary and one secondary. The primary focused on the development of a new solution concept in a 3D environment, while the secondary was to manufacture a physical prototype. Both of these goals were fulfilled since both CAD models and physical prototypes were created. The project went even further as several tests were performed on the prototypes of the final solution proposal.

In future car projects at VCC it is crucial that the recommended inclination angle for the drainage hoses should be followed. This is since stagnated water was shown to be one of the most critical factors for the occurrence of the sound phenomenon. In cases where the inclination angle is not sufficient it is recommended that the new drain plug concept with an integrated non-return valve should be implemented, in order to eliminate the risk of having problems with unwanted sounds.

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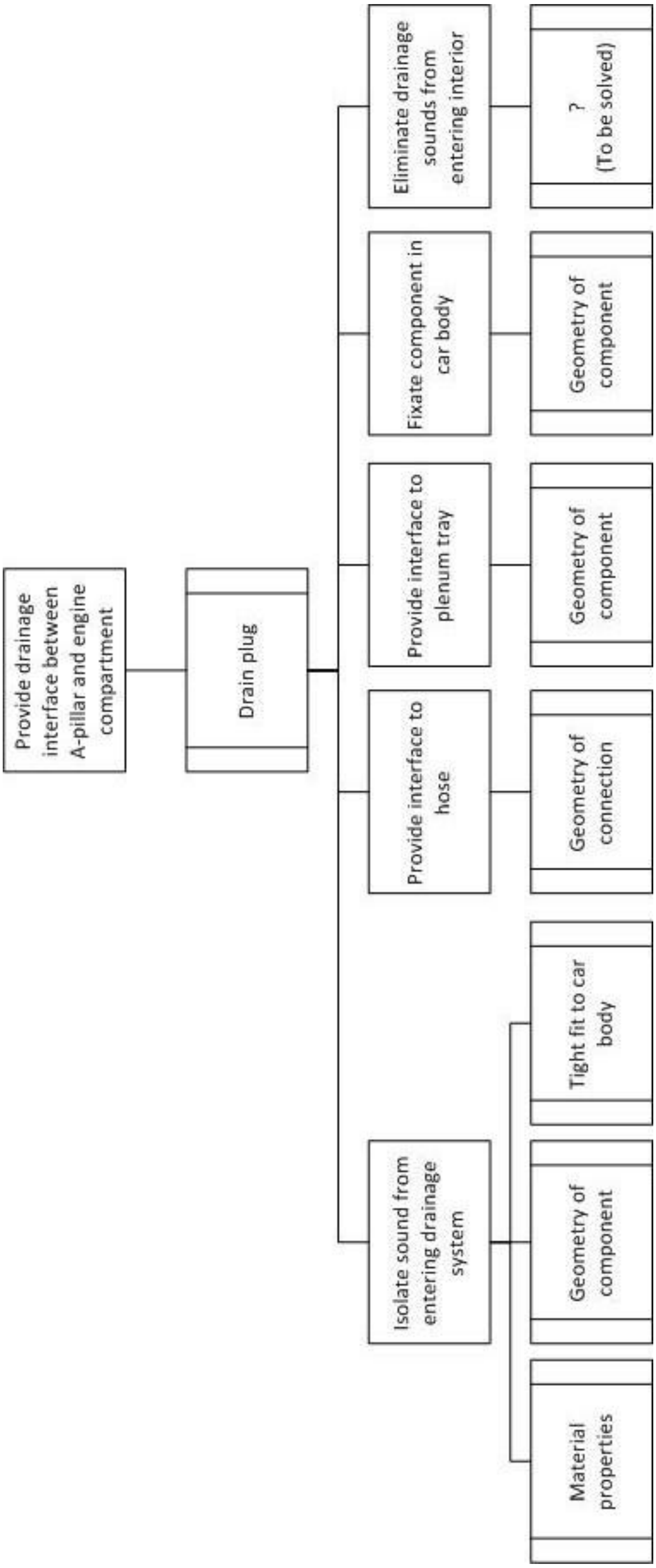
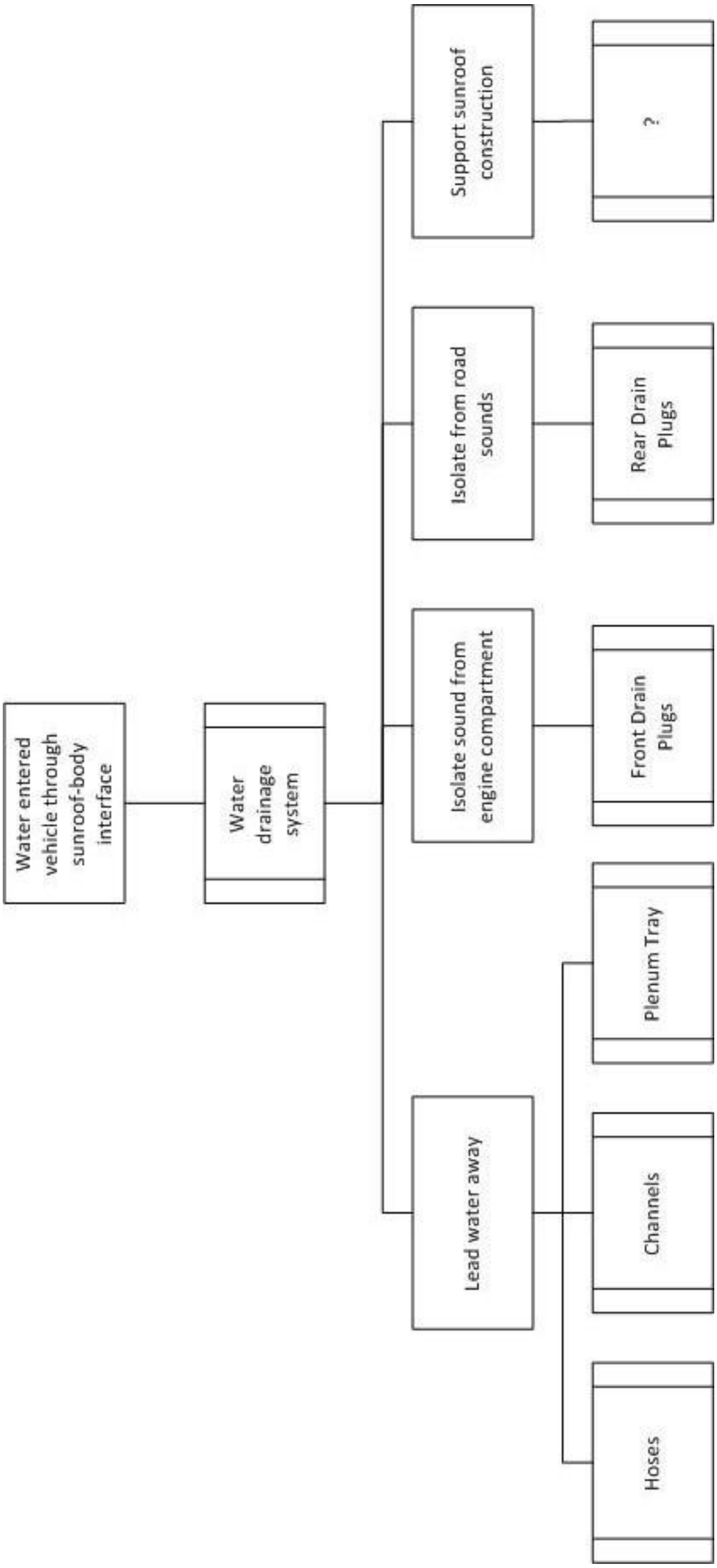
APPENDIX

Appendix A1. – Function-means-tree

Function-means-tree for the drain plug



Function-means-tree for entire drainage system



Appendix A2. - Requirement specification

This requirement list only contains the requirements stated during the project and by the master’s students, the ones stated by Volvo cars are classified. The list is an extraction from the whole and that is the reason for why some sections are blank and the numbering seems illogical.

Category	Req #	Requirement	Value	Description	Validation	Verification
Legal						
Functional						
	R 2.05	Dirt resistance		The drain plug must not clog from dirt	Drainage functionality	Engineering assessment, Prototype testing
	R 2.06	Watertightness		The drain plug and hose interface must be completely watertight	Corrosion resistance, quality impression	Engineering assessment
	R 2.07	Ice resistance		The drainage plug should not freeze tight during -5°C	Drainage functionality at low temperatures	Perform icing tests at -5°C on the drainage system
	D 2.01	Robustness		Service life should preferrably be 25 years	The complete car has a set requirement on service length, quality impression	Material specifications, engineering assessment, material ageing test
Usage Environment						
Environmental aspects						
	R 4.03	Recyclable		The component shall be fully recyclable'	Volvo´s environmental policy	Material specifications
	D 4.01	Design for Recycling		The drain plug should be designed in a way that facilitates and supports material recycling	In accordance with Volvo Cars environmental focus.	Evaluation of component design

Category	Req #	Requirement	Value	Description	Validation	Verification
Noise and vibrations						
	R 5.06	Elimination of sound phenomenon		The drain plug must totyally eliminate the identified unweanted sound phenomenon	Quality impression	Testing of drain plug prototype during drive tests of S- or V60
	D5.01	Shall block all noises		The drain plug shall block all noises from the engine compartment	Quality impression	Testing of drain plug prototype during drive tests of S- or V60
Manufacturing						
	D 6.01	Only one component		The drain plug should consist of a single component	Manufacturing cost, ease of assembly	Engineering assessment
	D 6.02	Assembly time	New ≤ Current	The assembly time requred for the new drain plug should be equal or shorter than the one for the current component	Ease of assemby	Engineering assesment, Assembly test of prototype
	D 6.03	Ease of assembly		The drain plug should be as easy as possible to assemble	Ease of assembly, assembly time	Engineering assesment, Assembly test of prototype

Category	Req #	Requirement	Value	Description	Validation	Verification
Geometry						
	R 7.10	Length	77.50 mm ≤ Length	The drain plug, from the top hole should be atleast 77.50 mm long. (10 mm safety margin)	Corrosion resistance, drainage functionality	CAD model assessment
	R 7.11	Gradient of component		The drain plug must provide a certain gradient to ensure that the water exits the car by use of gravitational force only	Ensurance of drainage functionality	Engineering assessment, prototype testing
	R 7.12	Fixation		The component shall be fixed in the hole in the car body of which it is mounted	Functionality, robustness	CAD model assessment
	R 7.13	Placement		The drain plug must be mounted in the existing hole in the car body, in connection with the engine compartment	No new holes allowed	CAD model assessment
	D 7.01	Lightweight part	new ≤ existing part	The drain plug should be as light or lighter then the existing part	Fuel consumption, logistics, material usage	Engineering assessment, CAD model evaluation
	D 7.02	Lightweight design		The drain plug should weigh as little as possible	Fuel consumption, logistics, material usage	Engineering assessment, CAD model evaluation

Category	Req #	Requirement	Value	Description	Validation	Verification
Cost						
	D 8.01	Cost per part	new ≤ existing part	The new part should be cheaper or as cheap as the current solutio	Save money	Cost calculations/estimations
	D 8.02	Cost of manufacturing		The new part shall be as cheap as possible to manufacture	Save money	Cost calculations/estimations
	D 8.03	Material per part		The new part should not use more material then the current solution	Spare the environment, minimise use of material, minimise weight	CAD model assessment
Modularity						
	R 9.01	Fit in S60 and V60		The component must fit in both S60 and V60	Manufacturing cost, ease of assembly	CAD model assessment
	D 9.01	Fit in all present models		The component should preferrably fit in several or all of Volvo´s car models	Manufacturing cost, ease of assembly	Engineering assessment, CAD model assessment
	D 9.02	Fit in future models		The component should preferably be able to be used in Volvo´s future car models	Manufacturing cost	Engineering assessment

Appendix A3. - Affinity diagram

Affinity diagram over the requirements of the drain plug.

Which are the requirements on the drain plug?

General Properties

- Shall consist of only one part (D)
- The new drain plug shall not consist of more material than the present (D)
- Must be recyclable (R)
- Shall be as cheap to manufacture as possible (D)
- Shall be as light as possible (D)
- Shall be robust, Service life – X number of years (D)

Manufacturability

- The drain plug shall only consist of one part (D)
- The new drain plug shall not consume more time to assemble than the present one (D)
- Shall be as easy as possible to assemble (D)
- Shall not cost more to produce than the existing drain plug (D)

Drainage Properties

- Must provide watertight connection between drain plug and hose (R)
- The new drain plug exit hole shall eliminate risk of surface tension of water (D)
- The drain plug must not clog from dirt (R)
- The drain plug must be long enough to exit in the engine compartment (R)
- The drain plug must have a gradient, so the water will move out of the car (R)

Existing Requirements

- The drain plug must fulfil the requirements stated by Volvo Cars (R)

Modularity

- Must fit in both S60 and V60 (R)
- Shall fit as many models as possible (D)

Noise reduction

- Shall block all noise from engine compartment (D)
- The drain plug must eliminate the inconvenient sound phenomena present today (R)

Placement

- Must be properly fixed in the hole in the car body in which it is mounted (R)
- The drain plug must use the existing exit hole in the car body, no new hole is allowed (R)

Appendix A4. - Kano model

	Must Be	More is Better	Delighters
Drain Plug	Must be recyclable (R)	Shall consist of only one part (D)	Shall fit as many models as possible (D)
	The drain plug must fulfil the requirements stated by Volvo Cars (R)	The new drain plug shall not consist of more material than the present (D)	Shall block all noise Frome engine compartment (D)
	Must provide watertight connection between drain plug and hose (R)	Shall be as cheap to manufacture as possible (D)	Shall be lighter than the existing part (D)
	The drain plug must use the existing exit hole in the car body, no new hole is allowed (R)	Shall be as light as possible (D)	Shall be cheaper to manufacture than the existing part (D)
	The drain plug must not clog from dirt (R)	Shall be robust, Service life - 25 years (D)	Shall consist of less material than the existing part (D)
	The drain plug should be at least 77,50 mm long, from first exit hole (R)	The new drain plug shall not consume more time to assemble than the present one (D)	
	The drain plug must have a gradient, so the water will move out of the car (R)	Shall be as easy as possible to assemble (D)	
	Must fit in both S60 and V60 (R)	The drain plug should be designed for recycling (D)	
	The drain plug must eliminate the inconvenient sound phenomena present today (R)		
	Must be fixed in the hole in the car body in which it is mounted (R)		

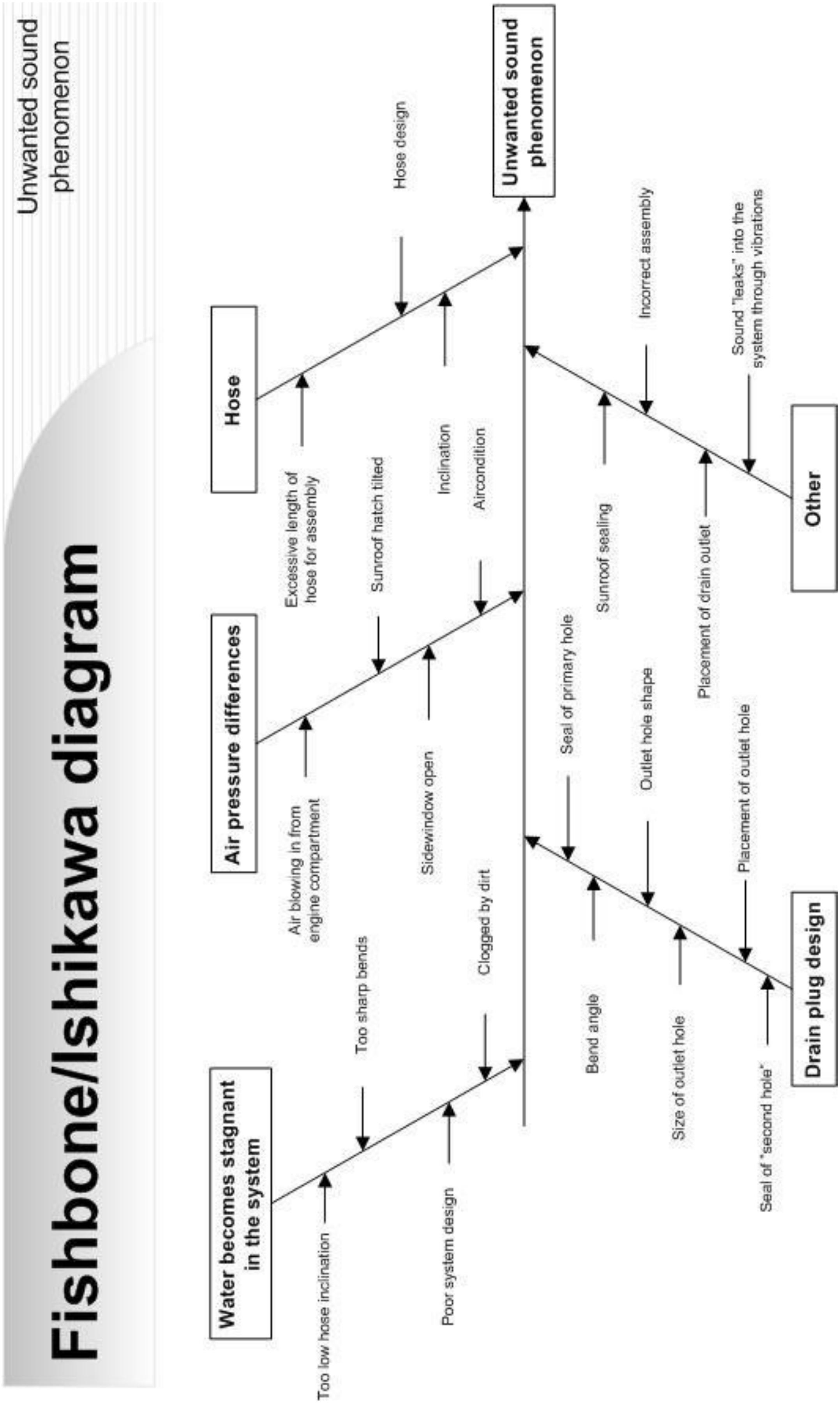
(R) – Requirements; (D) – Desires

Appendix A5. - Weighting matrix

Weighting matrix for the different desires. The desire in the left column is weighted against the ones in the top row. If the weighted desire is regarded as more important it receives one point, if less important, zero points and if regarded as equal the score is set to 0,5. The weights are then summarised and put in the sum column. The weighting is stated in the same table to the right, the weight is the value in percent.

Criterion																	
	D2.01	D4.01	D5.01	D6.01	D6.02	D6.03	D7.01	D7.02	D7.03	D8.01	D8.02	D8.03	D9.01	D9.02	Sum	Sum/Total	Weight (percent)
D2.01	-----	1	1	0	1	1	1	1	1	0	0	0	0,50	0	**7,5**	**0,085**	8,5
D4.01	0	-----	0	0	0	0	0	0	1	0	0	1	0	0	**2**	**0,023**	2,3
D5.01	0	1	-----	0	0	0	0	0,50	1	0	0	1	0	0	**3,5**	**0,040**	4
D6.01	1	1	1	-----	0	0	1	1	1	0	0	1	0	0	**7**	**0,080**	8
D6.02	0	1	1	1	-----	0,50	0,50	1	1	0	1	1	0	0	**8**	**0,091**	9,1
D6.03	0	1	1	1	0,50	-----	0,50	1	1	0	1	1	0	0	**8**	**0,091**	9,1
D7.01	0	1	1	0	0,50	0,50	-----	1	1	0	1	1	0	0	**7**	**0,080**	8
D7.02	0	1	0,50	0	0	0	0	-----	1	0	0	0	0	0	**2,5**	**0,028**	2,8
D7.03	0	0	0	0	0	0	0	0	-----	0	0	0	0	0	**0**	**0,000**	0
D8.01	1	1	1	1	1	1	1	0	1	-----	1	1	1	0	**11**	**0,125**	12,5
D8.02	0	1	1	1	0	0	0	1	1	0	-----	0	0	0	**5**	**0,057**	5,7
D8.03	0	0	0	0	0	0	0	1	1	0	1	-----	0	0	**3**	**0,034**	3,4
D9.01	0,50	1	1	1	1	1	1	1	1	0	1	1	-----	0	**11**	**0,119**	11,9
D9.02	1	1	1	1	1	1	1	1	1	1	1	1	1	-----	**13**	**0,148**	14,8

Appendix A6. – Ishikawa diagram



Appendix A7. – FMEA

FMEA (Failure Mode and Effects Analysis)

Main system	Part name	Dwg No.	Supplier
Drainage system (hose and drain plug),			**Primo**

Function	Date	Issued by	Status - hardware	Project	Issue
Drain water	**2011-01-31**	**Annie Mortensen/Simon Niemelä**		**Master thesis**	**1**

PART		CHARACTERISTICS OF FAILURE				RATING				ACTION-STATUS						
No	Function	Failure mode	Causes of failure	Effects of failure on part/system.	Testing	Po	S	Pd	RPN	Recommendations	Decisions taken	Po	S	Pd	RPN	Sign Resp. Dept/Sign
	Main function / Capabilities															
1.0	**Prevent drainage noise**															
1.1.1		Water becomes stagnant in the system	Too low hose inclination	Customer complaints, due to noise	Measurements, experiments	7	5	9	315							
1.1.2			Poor system design	Customer complaints, due to noise	Measurements, experiments	2	5	7	70							
1.1.3		Air pressure difference	Air blowing into hose from engine compartment	Customer complaints, due to noise. Reduced drainage capacity.	Air flow measurement in hose	10	5	10	500							
1.1.4			Air blowing through hose into interior, from engine compartment	Customer complaints, due to noise. Risk of bad smell entering interior	Air flow measurement											
1.1.5			Sidewindow opened	Customer complaints, due to noise	Air flow measurement in hose	10	5	5	250							
1.1.6			Sunroof hatch tilted	Customer complaints, due to noise	Air flow measurement in hose	10	5	5	250							
1.1.7		Hose	Hose design	Customer complaints, due to noise	Engineering assessment. Benchmarking	1	5	5	25							
1.1.8			Excessive length of hose for assembly	Customer complaints, due to noise. Failure of drainage function.	Assessment of assembly process. CAD assessment	10	5	5	250							
1.1.9		Drain plug design	Seal of primary hole	Customer complaints, due to noise	CAD assessment, noise measurements	2	5	8	80							
1.1.10			Seal of "second hole"	Customer complaints, due to noise	CAD assessment, Concept assessment,	10	5	1	50							
1.1.11			Placement of outlet hole	Customer complaints, due to noise	DoE, Engineering assessment	5	5	9	225							
1.1.12			Size of outlet hole	Customer complaints, due to noise	DoE, Engineering assessment	1	5	10	50							
1.1.13			Outlet hole shaped	Customer complaints, due to noise	DoE, Engineering assessment	5	5	10	250							
1.1.14			Bend angle (plug)	Customer complaints, due to noise	DoE, Engineering assessment	5	5	10	250							
1.1.15		Other	Sunroof sealing	Customer complaints, due to noise	Drainage test. Air tightness test	5	5	10	250							
1.1.16			Incorrect assembly	Customer complaints, due to noise. Failure of drainage function. Leakage	Assembly assessment, control of assembled system	7	5	4	140							
1.1.17			Placement of drain outlet	Customer complaints, due to noise.	DoE, Engineering assessment	5	5	10	250							
1.1.18			Sound "leaks" into the drainage system through	Customer complaints, due to noise.	Engineering assessment	2	5	3	30							
1.2	**Water drainage**								0							
1..2.1		Water becomes stagnant in the system	Clogged by dirt	Failure of drainage function. Water leakage.	Drainage test. Optical assessment	4	8	10	320							
1..2.2			Too sharp bends	Customer complaints, due to noise. Reduction of drainage capacity	Measurements, experiments	5	5	10	250							
		Water leakage	Untight fittings between hose and plug	Water leakage	Drainage test	2	8	2	32							

Appendix A8. - Data collection plan

What?	Why?	How?	Where?	When?
Measure available space for component	To see available space	DMU, CAD, Physical product evaluation	PVÖS23, PVÖ assembly plant	w.5-6
Benchmarking of internal systems	To find out what solutions there are, material used etc.	Interviews, DMU	PVÖS23	w.5-6
Benchmarking of competitors	To find out what solutions there are, material used etc.	Database search A2MAC1, Internet, Car dealers, Database search Patents	PVÖS23	w.6
Benchmarking of similar systems for other applications	To find out what solutions there are, material used etc.	Internet, Patent Databases, Interviews	PVÖS23	w.6
Data from flow- and pressure simulations	To identify problem areas, increase understanding	Interviews, documentation studies	PVÖS23	w.6
Manual water flow experiments on V60, XC60	To identify problem areas, increase understanding. Measure variation	Pour a specified amount of water through one of the front hoses, collect the water at the other end and calculate how much that has passed through the system. Repeat the experiment on 5-10 cars to measure variation	PVÖS?	w.7
Assemby time	To compare against requirements	Time studies, documentation	TC assembly plant, Torslanda	w.7
Measure air inflow from engine compartment, through hose, into interior	To find out how much air that flows through the system	Blow smoke through hose? Drive with hose unattached to sunroof system	PVÖS?	w.7
Compare virtual model with reality	To see if the model corresponds to reality	Study of CAD model, measurements on real car	PVÖS?	w.8
Compare measurements on production vehicle with CATIA measurements	Too see if reality corresponds to requirements	Measurements on cars in production. Measurements taken from CATIA model	PVÖS, TC	w.8
Compare a sample of cars with the modified hose position with a sample of cars with the original position	To measure variation and to calculate standard deviation	Pour a specified amount of water through one of the front hoses, collect the water at the other end and calculate how much that has passed through the system. Repeat the experiment on 5-10 cars.	Volvo area?	w.8

Appendix A9. - Experiment description for CFD

Purpose:

Verify if there is a pressure difference between the upper and lower hose openings and approximate how large this is.

Tools, Measuring equipment, Test facilities:

CFD department at Volvo

Test Parameters:

Car:

- Volvo model S60 or V60

Driving conditions:

- 100 km/h
- Tilted sunroof
- Normal atmospheric pressure

Test Sequence:

One simulation run

Requirements:

- Simplifications in the simulation model may not compromise the end result in a way that could make it unreliable.

Appendix A10. - Experiment description for verification of water traps

Purpose:

To verify the position and number of water traps in the sunroof systems´ front drain hoses

Tools, Measuring equipment, Test facilities:

- A complete car body of Volvo model S60 or V60
- A drain hose, regular as well as transparent
- Clips for fastening according to production car
- A fibre optic camera
- Graduated cylinder, water
- Test facility: Strength laboratory, PV24

Test Parameters:

- Adding of 10 ml of water at sunroof end of hose

Test Sequence:

- Add water
- Wait 2 min and 30 seconds
- Use fibre optic camera to identify position and number of water traps, alternatively conduct optical assessment of transparent hose

Requirements:

The hoses must be mounted according to production vehicles

Appendix A11. - Experiment description for MSA

Purpose:

Verify that the measurement method is good enough for further use.

Tools, Measuring equipment, Test facilities:

Garage at VCC Torslanda, PV27

Graduated cylinder, plastic funnel, pipette and measurement protocol

Test Parameters:

Car:

- Volvo model XC60

Amount of water used:

- 2, 4, 6, 8 and 10 ml of water should be poured down, once per A pillar drainage system and operator

Operators:

- 3 different operators should perform the same experiment

Waiting time:

- After pouring down the water through the drainage system, 2 min and 30 seconds should pass and then the collected water should be measured

Test Sequence:

- Pressurised air should blow dry and clean the drainage system for 30 seconds between and before each test.
- The amount of water 2, 4 ,6, 8 or 10 ml should be measured in graduated cylinder
- A glass should be placed beneath the drain plug to collect the water
- The water is then poured down the drainage system and collected beneath the plug
- After 2 min and 30 seconds the collecting glass is removed
- The water from the glass is poured into a graduated cylinder through a funnel and then measured

Requirements:

The amount of collected water must be measurable

Appendix A12. - MSA protocol

MSA result form - Sunroof system drainage experiment XC60

Car: XC60 reg nr. HMH489
Date: 110215, 110216 Location: Vagnverkstad PV

Operator	Amount of fluid [ml]	**Result [ml]** (amount of fluid collected)	Notes:
1	2	1,1	
2	2	1,2	2 min 30 sec
3	2	1,1	Right side of vehicle
1	4	3,2	
2	4	2,6	OP1: Simon
3	4	2,9	OP2: Niclas
1	6	5,2	OP3: Annie
2	6	4,6	
3	6	5,0	
1	8	6,3	
2	8	6,0	
3	8	6,3	
1	10	9,2	
2	10	8,6	
3	10	8,9	
1	2	1,1	
2	2	0,8	
3	2	1,0	
1	4	3,2	
2	4	2,7	
3	4	2,8	
1	6	5,1	
2	6	4,8	
3	6	4,8	
1	8	6,0	
2	8	7,3	
3	8	6,8	
1	10	9,1	
2	10	9,1	
3	10	8,8	

Appendix A13. - MSA computational data from minitab

Results from minitab ANOVA calculations

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Fluid	4	225,542	56,3855	564,561	0,000
Operator	2	0,155	0,0776	0,777	0,492
Fluid * Operator	8	0,799	0,0999	1,174	0,375
Repeatability	15	1,276	0,0851		
Total	29	227,772			

Alpha to remove interaction term = 0,25

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Fluid	4	225,542	56,3855	624,921	0,000
Operator	2	0,155	0,0776	0,860	0,436
Repeatability	23	2,075	0,0902		
Total	29	227,772			

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0,09023	0,95
Repeatability	0,09023	0,95
Reproducibility	0,00000	0,00
Operator	0,00000	0,00
Part-To-Part	9,38255	99,05
Total Variation	9,47277	100,00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	0,30038	1,8023	9,76
Repeatability	0,30038	1,8023	9,76
Reproducibility	0,00000	0,0000	0,00
Operator	0,00000	0,0000	0,00
Part-To-Part	3,06309	18,3786	99,52
Total Variation	3,07779	18,4667	100,00

Number of Distinct Categories = 14

Appendix A14. - Experiment description for water drainage measurements

Purpose:

To measure the amount of water that is stagnating in the drainage system, the front hoses.

Tools, Measuring equipment, Test facilities:

A complete car (S60 or V60) with A pillar panel and plenum cover removed. Graduated cylinder, plastic funnel, pipette, water and measurement protocols.

Measurements carried out inside one of the garages at VCC, PV27.

Test Parameters:

Amount of water
10 ml of water applied to both front hoses at the sunroof end.

Duration
Collection of water after 2 min 30 seconds at the lower end of the drain plug

Climate
Room temperature

Test Sequence:

- Blow the hoses clean with pressurized air for 5 seconds
- Measure up 10 ml of water in a graduated cylinder
- Apply to hose at sunroof connection
- Collect water in a glass cup at the end of drain plug after 2 min and 30 seconds
- Measure the amount of water collected in a graduated cylinder and note results

Requirements:

The amount of water collected must be measurable

Appendix A15. - Water measurement protocols

Measurement protocol - Sunroof system drainage experiment						
Car:	S60, KZW568					
Date:	110217		Location:	Vagnverkstaden, PV27		
Operator	**Amount of fluid [ml]**	**Result [ml], original position** (amount of fluid collected)		**Result [ml], modified position** (amount of fluid collected)		**Notes:**
		Right	Left	Right	Left	Op1 - Simon
1	10	7,5	5,8	8,1	8,1	Op2 - Annie
1	10	6,4	4,6	8,6	8,3	
1	10	7,1	4,3	8,2	8,8	5 sec blowing of pressurized air
1	10	4,8	4,2	8,5	8,3	between measurements
1	10	6,2	4,8	8,6	8,1	
2	10	5,8	4,2	8,4	6,2	
2	10	6,6	4,2	8,2	8,0	
2	10	6,0	3,2	9,2	8,0	
2	10	5,2	4	9,2	7,0	
2	10	6,2	3,8	8,4	8,0	

Measurement protocol - Sunroof system drainage experiment						
Car:	S60, BGY251					
Date:	110218	Location:	Vagnverkstad, PV27			
Operator	**Amount of fluid [ml]**	**Result [ml], original position** (amount of fluid collected)		**Result [ml], modified position** (amount of fluid collected)		**Notes:**
		Right	Left	Right	Left	Op1 - Simon
1	10	7,2	6,8	8,3	8,4	Op2 - Annie
1	10	7,1	6,6	8,3	8,4	
1	10	7,3	6,6	8,5	8,8	
1	10	6,8	6,8	8,4	8,5	5 sec blowing of pressurized air
1	10	7,0	6,4	8,3	8,4	between measurements
2	10	7,2	7,0	8,6	8,6	
2	10	6,8	7,0	8,6	9,0	Red hoses
2	10	7,4	6,4	8,6	8,4	
2	10	5,0	7,0	8,4	7,8	
2	10	6,6	7,0	8,6	9,0	

Measurement protocol - Sunroof system drainage experiment						
Car:	V60, LDN044					
Date:	110218	Location:	Vagnverkstad, PV27			
Operator	**Amount of fluid [ml]**	**Result [ml], original position** (amount of fluid collected)		**Result [ml], modified position** (amount of fluid collected)		**Notes:**
		Right	Left	Right	Left	Op1 - Simon
1	10	5,0	7,4	8,2	8,5	Op2 - Annie
1	10	3,9	6,8	7,2	8,6	
1	10	1,7	6,6	7,3	8,9	
1	10	2,4	7,0	7,2	8,9	5 sec blowing of pressurized air
1	10	2,6	7,4	7,8	8,8	between measurements
2	10	2,6	7,2	6,8	9,2	
2	10	3,0	6,8	7,0	9,2	Black hoses
2	10	2,8	6,4	6,8	8,6	
2	10	4,4	7,0	6,8	9,4	
2	10	2,2	8,0	4,6	9,4	

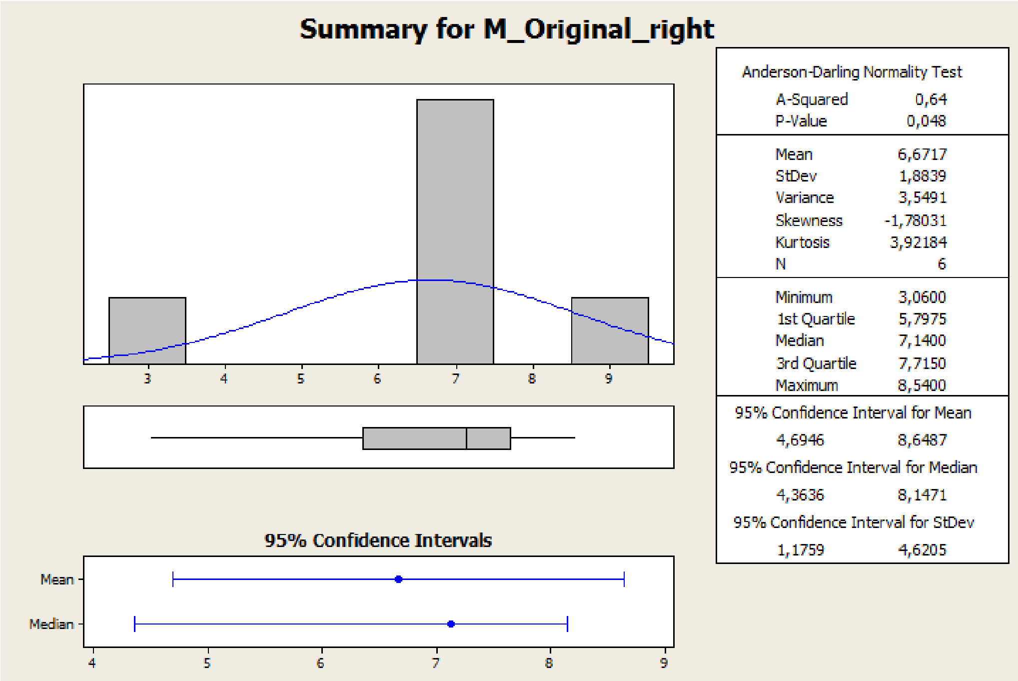
Measurement protocol - Sunroof system drainage experiment						
Car:	DMX354, S60					
Date:	110221	Location:	Vagnverkstaden PV27			
Operator	**Amount of fluid [ml]**	**Result [ml], original position** (amount of fluid collected)		**Result [ml], modified position** (amount of fluid collected)		**Notes:**
		Right	Left	Right	Left	Op1 - Simon
1	10	7,0	6,6	6,7	6,2	Op2 - Annie
1	10	7,0	6,6	7,0	6,0	
1	10	7,1	6,8	6,9	5,8	
1	10	6,8	6,7	6,9	5,8	5 sec blowing of pressurized air
1	10	6,6	6,6	7,0	5,3	between measurements
2	10	6,2	7,6	7,4	8,6	
2	10	6,6	6,8	6,6	7,2	Red hoses?
2	10	6,6	6,6	7,0	7,0	
2	10	6,4	6,0	5,6	6,6	
2	10	6,8	6,4	7,4	5,6	

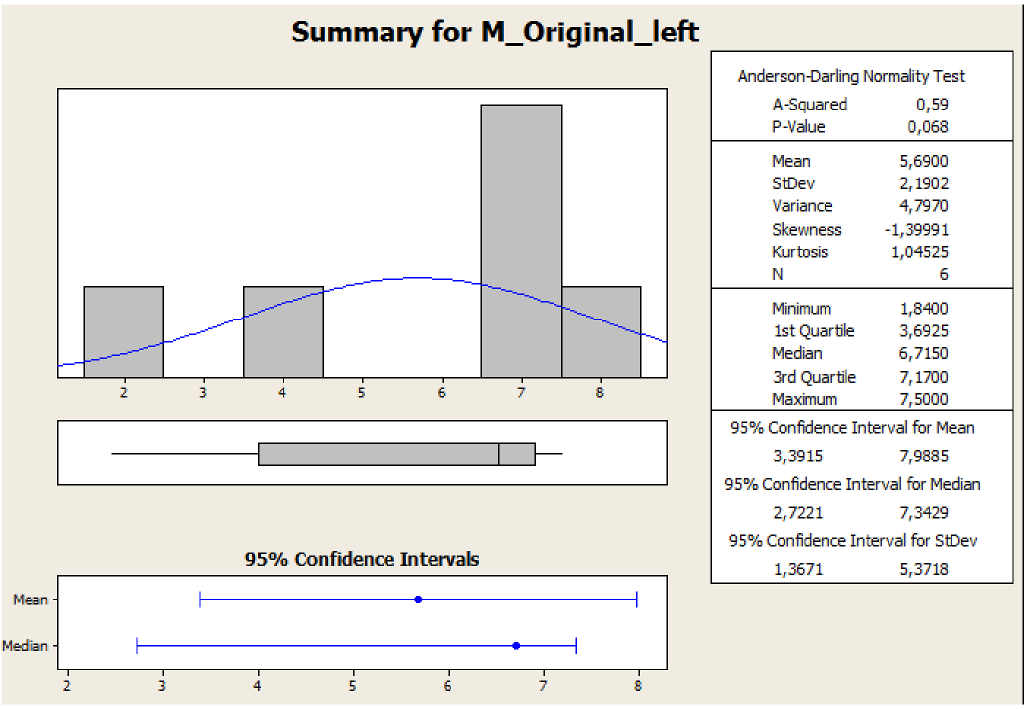
Measurement protocol - Sunroof system drainage experiment						
Car:	MOR344, V60					
Date:	110221	Location:	Vagnverkstaden PV27			
Operator	**Amount of fluid [ml]**	**Result [ml], original position** (amount of fluid collected)		**Result [ml], modified position** (amount of fluid collected)		**Notes:**
		Right	Left	Right	Left	Op1 - Simon
1	10	6,9	7,4	8,8	8,5	Op2 - Annie
1	10	7,0	7,6	9,0	8,4	
1	10	7,4	7,6	8,2	8,6	
1	10	8,0	7,6	8,7	8,3	5 sec blowing of pressurized air
1	10	7,3	7,4	9,0	8,4	between measurements
2	10	7,4	7,6	8,8	8,4	
2	10	7,4	7,4	9,0	8,6	Black hoses
2	10	7,4	7,4	9,2	8,8	
2	10	8,0	7,6	9,0	8,2	
2	10	7,6	7,4	9,4	8,8	

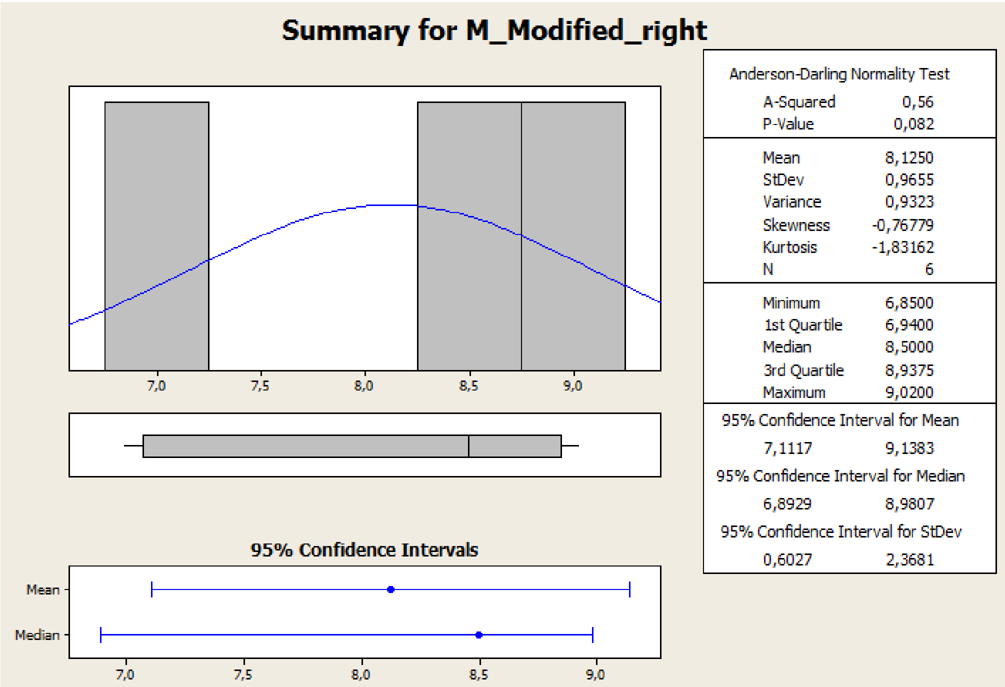
Measurement protocol - Sunroof system drainage experiment						
Car:	AAX103, V60					
Date:	110225		Location:	Vagnverkstaden, PV27		
Operator	**Amount of fluid [ml]**	**Result [ml], original position** (amount of fluid collected)		**Result [ml], modified position** (amount of fluid collected)		**Notes:**
		Right	Left	Right	Left	
1	10	8,2	1,4	8,8	7,5	Op1 - Simon
1	10	7,2	1,6	9,0	7,8	Op2 - Annie
1	10	7,4	1,4	9,1	7,8	
1	10	7,4	1,8	9,2	6,7	5 sec blowing of pressurized air
1	10	7,4	4,2	8,8	7,4	between measurements
2	10	6,6	1,4	9,1	6,8	
2	10	7,8	1,6	9,2	7,6	
2	10	7,2	1,8	9,0	7,6	Black hoses
2	10	7,6	1,4	9,0	6,0	
2	10	7,6	1,8	9,0	6,4	

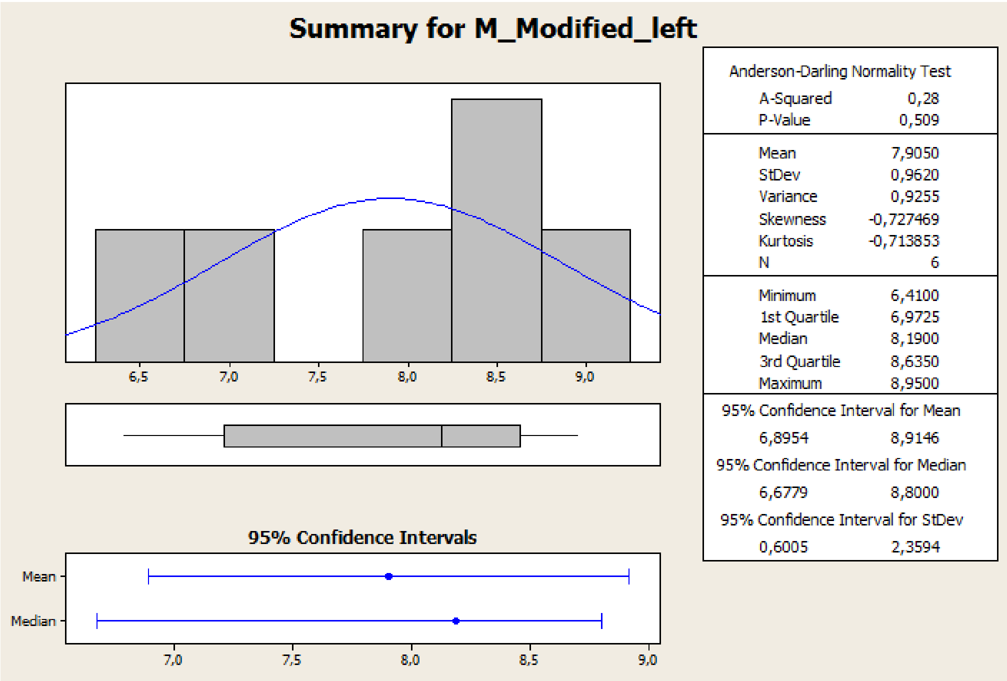
Appendix A16. - Summary, statistical calculations from Minitab

In this appendix the different statistical calculations carried out in the software Minitab are displayed. Each picture is showing a summary of the normal distribution for the mean-mean ($\hat{\mu}$) value of each hose position and side of car respectively.









Mean-mean values for the drained water for each of the vehicles.

Mean	M_Original_right	M_Original_left	M_Modified_right	M_Modified_left
S60 KZW568	8,54	4,31	8,54	7,88
S60 BGY251	6,84	6,76	8,46	8,53
V60 LDN044	3,06	7,06	6,97	8,95
S60 DMX354	6,71	6,67	6,85	6,41
V60 MOR344	7,44	7,5	8,91	8,5
V60 AAX103	7,44	1,84	9,02	7,16
Mean-Mean	6,671666667	5,69	8,125	7,905

Appendix A17. - Experiment description for water drainage measurements with applied washing-up liquid

Purpose:

To measure the amount of water that is stagnating in the drainage systems´ front hoses when the influence of friction and surface tension is minimised.

Tools, Measuring equipment, Test facilities:

A complete car (XC60) with A pillar panel and plenum cover removed. Graduated cylinder, plastic funnel, pipette, water and measurement protocols.

Measurements carried out inside one of the garages at VCC, PV27.

Test Parameters:

Amount of water

- 10 ml of water, mixed with washing-up liquid, applied to both front hoses at the sunroof end.

Duration

- Collection of water after 2 min 30 seconds at the lower end of the drain plug

Climate

Room temperature

Test Sequence:

- Blow the hoses clean with pressurized air for 5 seconds
- Pour 10 ml of water in a graduated cylinder
- Apply to hose at sunroof connection
- Collect water in a glass cup at the end of drain plug after 2 min and 30 seconds
- Measure the amount of water collected in a graduated cylinder and note results

Requirements:

The amount of water collected must be measurable

Appendix A18. - Measurement data from water measurements with washing-up liquid in the water

Measurement protocol - Sunroof system drainage experiment						
Car:	HUR508, XC60					
Date:	110301		Location:	Vagnverkstaden, PV27		
Operator	**Amount of fluid [ml]**	**Result [ml], without soap** (amount of fluid collected)		**Result [ml], with soap** (amount of fluid collected)		**Notes:**
		Right	Left	Right	Left	
1	10	8,8	8,7	9	8,8	Op1 - Simon
1	10	8,9	8,6	9	9	Op2 - Annie
1	10	9	8,4	9,2	8,9	
1	10	9,2	8,4	9,1	8,9	5 sec blowing of pressurized air
1	10	8,9	8,4	9	9	between measurements
2	10	9	8,2	9,4	9	
2	10	9,4	9	9,4	9	
2	10	9	8,8	9,2	9	
2	10	9,2	9	9,4	9	
2	10	9,4	9	9,2	9,2	

Mean value		9,08	8,65	9,19	8,98
Difference between with and without washing up liquid				0,11	0,33

Appendix A19. - Experiment description Design of Experiments

Purpose:

Verification and measurements of the influence of a certain set of parameters on the unwanted sound phenomenon

Tools, Measuring equipment, Test facilities:

- A complete car, Volvo S60. A pillar cover removed, access to drain plug provided through loosened plenum cover.
- 3 engineers to assess sound level
- Measurement protocols
- Graduated cylinder, water
- Tests carried out at VCC´s proving ground Hällered

Test Parameters:

- Sunroof drainage system, front hoses positioned either above or beneath the clip closest to the drain plug
- Cross-shaped or round opening of the drain plug
- Driving speed: 80 km/h to 110 km/h

Test Sequence:

- Application of water to the front hoses of the sunroof drainage system
- Set up of test parameters according to a 2-level full factorial experiment design
- Drive one lap around the oval test track at Hällered
- Assess the sound level of the unwanted sound phenomenon

Requirements:

Unwanted sound phenomenon must be assessable

Appendix A20. - Result summary Design of Experiments

All calculations have been carried out in the statistical software Minitab. The experiments were conducted at VCC´s proving ground Hällered, Sweden at the 7th of March 2011. The experiment design was a full factorial with factors at two levels.

Factor\Level	**-1**	**1**
Inclination:	Placed in clip	Placed beneath clip
Speed:	80 km/h	110 km/h
End opening of drain plug:	Original opening, Cross shaped	Widened opening, round

Grading	**Assessment scale**
0	No Sound
1	Weak sound
3	Intermediate Sound
9	Loud Sound

StdOrder	**RunOrder**	**Inclination**	**Speed**	**Opening on drain plug**	**y**
7	**1**	-1	1	1	3
6	**2**	1	-1	1	3
8	**3**	1	1	1	9
4	**4**	1	1	-1	9
3	**5**	-1	1	-1	3
2	**6**	1	-1	-1	9
5	**7**	-1	-1	1	3
1	**8**	-1	-1	-1	3

Factorial Fit: y versus Inclination; Speed; drain plug opening

```
Estimated Effects and Coefficients for y (coded units)

Term                                  Effect     Coef
Constant                                       5,2500
Inclination                           4,5000   2,2500
Speed                                 1,5000   0,7500
drain plug opening                   -1,5000  -0,7500
Inclination*Speed                     1,5000   0,7500
Inclination*drain plug opening       -1,5000  -0,7500
Speed*drain plug opening              1,5000   0,7500
Inclination*Speed*drain plug opening  1,5000   0,7500
```

Appendix A21. - Experiment description for Ad hoc tests performed at Proving ground Hällered

Purpose:

To identify and verify different scenarios that affects the sound phenomenon.

Tools, Measuring equipment, Test facilities:

- A complete car, Volvo S60. A pillar cover removed, access to drain plug provided through loosened plenum cover.
- 3 engineers to assess sound level
- Measurement protocols
- Graduated cylinder, water
- Tests carried out at VCC´s proving ground Hällered

Test Parameters:

- Sunroof drainage system, front hoses positioned either above or beneath the clip closest to the drain plug
- Different drain plugs as well as AC ON/OFF
- Driving speed: 80 km/h to 110 km/h

Test Sequence:

- The drain plug is changed to a new one
- Water is poured down the sunroof drainage system
- Entering the test track and driving the car in different speeds to enable the sound phenomenon to occur
- The test is finished when the sound emerges or when everything has been done in order to provoke the sound phenomenon without success
- The test cycle is the repeated

Requirements:

Unwanted sound phenomenon must be assessable

Appendix A22. - Results from ad hoc tests at proving ground Hällered

Test drive at Hällered	Date: 11-03-07
Car: BGY251	

Test	Notes:
Elongated drain plug that pass through the plenum tray	3
Test with small non-return valve, lid facing up	0
Test with small non-return valve, lid facing down	3
Test with small non-return valve, lid facing side	0
Test with change of angle of outlet hole	3
Test with opening of different side windows, roof top closed	3
Test with open roof top entirely	3
Test with AC on/off	max AC eliminates sound
Test with Sound trap	3
Test with longer version of small non-return valve, lid facing up	0
Test with big non-return valve	3
Test with small non-return valve, small with tape to make it open in original position	3
Test with old drain plug with smaller opening	3

Small non-return valve: Y0 drain plug from Functional black trim

Grading	Assessment scale
0	No Sound
1	Weak sound
3	Intermediate Sound
9	Loud Sound

Appendix A23. - Experiment description for ice testing of drain plug

Purpose:

Investigate if different drain plug solutions will work properly in cold climates. Test how the system will work in below zero degrees when exposed to water, in e.g. a car wash.

Tools, Measuring equipment, Test facilities:

- Climate chamber
- Different drain plugs
- Fixture for drain hose and plug
- Graduated cylinder, plastic funnel, protocol and water
- Timer

Test Parameters:

Amount of water applied

- 0,5 litres

Duration

- Approximately five hours in the climate chamber

Climate

- -5°C

Test Sequence:

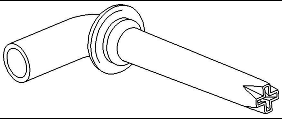
- The drain hose and plug will be placed in a fixture that to some extent matches its original position in the cars
- 0,5 litre of water is applied to the drainage system
- The time is measured for how long time it takes for the system to drain 0,4 litres of water. This measurement will only be performed once for reference, but the water will be applied each time.
- The test fixture will then be placed in a climate chamber
- The climate chamber will be stable at -5 °C
- After one hour, the drainage system and fixture will be removed from the climate chamber
- 0,5 litres of water is applied to the drainage system
- The time is measured for how long time it takes for the system to drain 0,4 litres of water.
- The drainage system will then be placed in room temperature for 20 minutes.
- Repeat

Requirements:

The drain plug must be able to drain water

Appendix A24. - Results from icing test on drain plugs

The time it took for the drain plugs to drain 400 ml of water was measured, that is the drainage time mentioned. One reference measurement was performed before the test begun and then again after the test rig was placed in the climate chamber. However the comments are the interesting part since the measured drainage time varies a lot depending on pouring speed and the ones monitoring the stopwatch.

Date: 31 March - 15 April	**Drainage time**		**Location:** PVT building
Drain plug design	**Before test**	**During test**	**Notes:**
Present drain plug in S60V60	23,6 s		
		30 s	Semi-frozen, leaked water and opened quick
		23,6 s	Not frozen
		39,7 s	Semi-frozen, leaked water and opened quick
		28 s	Not frozen
Y0 drain plug	26,7 s		
		29,3 s	Semi-frozen, leaked water and opened quick
		43 s	Frozen, but opened itself
	14,4 s		
		24 s	Semi-frozen, leaked water and opened quick
		20,4 s	Semi-frozen, leaked water and opened quick
		25 s	Not frozen
		21 s	Not frozen
Big rubber plug with lid	16,9 s		
		23,8 s	Semi-frozen, leaked water and opened quick
		17,4 s	Semi-frozen, leaked water and opened quick
Drain plug from Audi	24,3 s		
		34,6 s	Semi-frozen, leaked water and opened quick

Appendix A25. - Experiment description for test drive TT-track, noise reduction solutions

Purpose:

Investigate if different modifications to drainage system will reduce unwanted sound phenomenon. New hose, new clip, new clip position and right steered car will be tested.

Tools, Measuring equipment, Test facilities:

- Test drives conducted at the TT-track
- Three cars used, one S60, one V60 and one right steered S60
- S60 equipped with larger, transparent, hose (ID 12 mm)
- V60 equipped with different clips and hose positioning. Hose positioning means removing middle clip and placing hose above lower clip.

Test Parameters:

Number of laps at test track

2-3 laps

Amount of water

1 dl water was added to the drainage system

Test Sequence:

- Preparations are carried out prior to test drive (changing of clips, modifying hose position)
- Water is then added to the system
- The car is driven around the test track at speeds between 60-140 km/h
- Sound level is subjectively judged during test drive and noted in protocol
- Water is added in between different test setups

Requirements:

Unwanted sound must be verified to occur in respective vehicle before modifications are carried out.

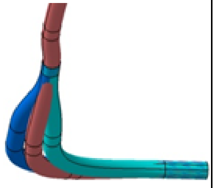
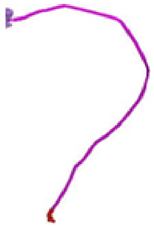
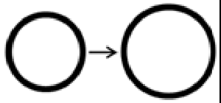
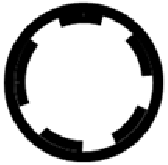
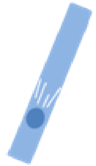
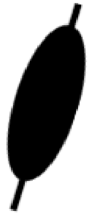
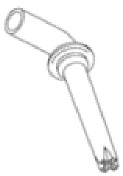
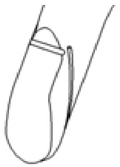
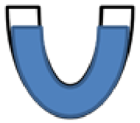
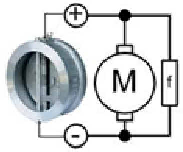
Appendix A26. - Test results from test drive at TT-track

Testdrive - Minor noise reduction solutions(?)

Date: 110330
Location: TT-test track

Test car	Test run	Modification	Noise level (0-3-6-9)	Notes:
BGY 251		Larger hose (12mm ID)		
	1		3	Higher speed required before sound started.
				The water "wanders" all the way up through the hose.
	2		3	It looks like the water "chunk" explodes and then regroups again during every "pop sound".
KKJ 284		Different clip, bottom position.		
	1		3	28mm clips, Sound starts at 110 km/h
	2		6	Sound starts at 90 km/h. More splashing sounds could be heard than before.
				The sound could be heard distinctly down to 65 km/h
		Remove middle clip and place hose above lower clip		(No refill of water in between test runs)
	1		0	
	2		6	Sound heard between 90 km/h - 105 km/h
	3		0	
?		Steering on the right side, Japanese version		
	1		6	50 mph, sound could be heard from both sides
	2		6	Sound from right side only
	3		6 (9?)	Sound from right side only

Appendix A27. - First Morphological matrix for basic design concepts

Function	Solution 1	2	3	4	5	6	7
Remove water/Hose routing	Hose in original position 	Hose mounted in modified clip 	Hard fix plastic part with forced inclination 	Rerouting of hose 			
Reduce/change water movement, backwards	Original hose 	Bigger hose Ø 	Hose inner structure with smaller canals 	Ribbed/bellowed inner structure of hose 	Hose with inner spiral 	Low friction treated inner hose surface 	Hose with rubber bulb 
Reduce/Remove pressure difference	Original plug 	Soft non-return valve 	Hard non-return valve 	Non-return valve which closes when pressurised 	Bigger water-lock 	Electrical non-return valve 	

Appendix A28. - Elimination matrix

Criteria fulfilment:
(+) Yes
(-) No
(0) Might work when combined
(?) More info needed
(!) Check with Specification

Decision:
(+) Continue
(-) Remove
(?) More info needed
(!) Check with Specification

Elimination Matrix for	Elimination factors							
Concept alternative	Solves Main Problem	Fulfils all component demands	Compatible/Realizable	Reliable	Cost efficient	Enough Information	Comment	Decision
1. Hose in original position	0	+	+	+	+	+	Doesn’t work alone, needs to be combined	+
2. Hose mounted in modified clip	-	+	+	+	+	+	Didn’t work in test performed	-
3. Hard fix plastic part with forced inclination	-	+	+	+	+	+	Will not solve the main problem	-
3. Rerouting of hose	+	+	-	+	+	+	Can’t be implemented in affected car models	-
4. Original hose	0	+	+	+	+	+	Doesn’t work alone, needs to be combined	+
5. Bigger hose Ø	+	+	?	+	+	-	Needed size don’t fit in A pillar	-
6. Hose inner structure with smaller canals	?	?	+	+	+	-	Needs to be tested	+
7. Ribbed/bellowed inner structure of hose	?	+	+	+	+	-	Needs to be tested	+
9. Hose with inner spiral	?	+	+	+	+	-	Needs to be tested	+
10. Low friction treated inner hose surface	-	?	+	?	?	-	Doesn’t work	-
11. Hose with rubber bulb	+	+	+	+	+	-	Needs to be investigated and tested	+
12. Original drain plug	0	+	+	+	+	+	Doesn’t work alone, needs to be combined	+
13. Soft non-return valve	+	+	+	+	+	+	Have worked in tests	+
14. Non-return valve with hatch	+	+	+	+	+	+	Should work	+
15. Non-return valve which closes when pressurised	+	+	?	?	?	-	Needs to be investigated more	+

16. Bigger water-lock	+	-	+	-	+	+	Might freeze/collect dirt and damage the system	-
17. Electrical non-return valve	+	?	+	+	-	-	Too complex and expensive	-

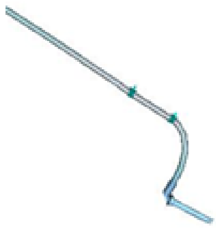
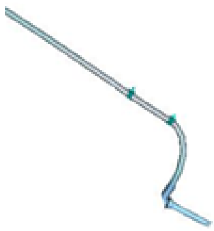
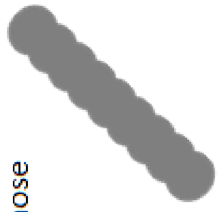
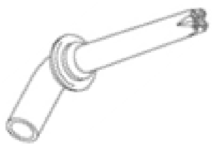
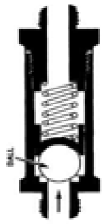
Appendix A29. - Pugh matrix

1. Datum: Hose in original position – Original hose – Original drain plug
2. Hose in original position – Hose inner structure with small canals - Original drain plug
3. Hose in original position – Ribbed/bellowed inner structure of hose - Original drain plug
4. Hose in original position – Hose with inner spiral - Original drain plug
5. Hose in original position – Hose with rubber bulb - Original drain plug
6. Hose in original position – Original hose – Soft non-return valve
7. Hose in original position – Original hose – non-return valve with hatch
8. Hose in original position – Original hose – Non-return valve which closes when pressurised

Desires		**Alternative**							
Screening 1		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
D2.01	**Robustness**	**DATUM**	0	0	-	0	-	-	-
D4.01	**Design for Recycling**		0	0	0	0	0	0	-
D5.01	**Shall block all noises**		+	+	+	+	+	+	+
D6.01	**Only one component**		0	0	0	-	0	0	-
D6.02	**Assembly time**		0	0	0	-	0	0	0
D6.03	**Ease of assembly**		0	0	0	-	0	0	0
D7.01	**Lightweight part**		0	0	-	-	0	0	-
D7.02	**Lightweight design**		0	0	-	-	0	0	-
D8.01	**Cost per part**		-	-	-	-	0	-	-
D8.02	**Cost of manufacturing**		-	-	-	-	0	-	-
D8.03	**Material per part**		0	0	-	-	0	-	-
D9.01	**Fit in all present models**		0	0	0	-	0	0	0
D9.02	**Fit in future models**		0	0	0	-	0	0	0
Sum +			1	1	1	1	1	1	1
Sum 0			10	10	6	2	12	8	4
Sum -			2	2	6	10	1	4	8
Net Value			-1	-1	-5	-9	0	-3	-7
Ranking			2	3	6	8	1	5	7
Further Development			Yes	Yes	Yes	No	Yes	Yes	Yes

Desires Screening 2		**Alternative**							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
D2.01	**Robustness**	+	+	+	0	0	**D A T U M**	0	-
D4.01	**Design for Recycling**	0	0	0	0	0		0	-
D5.01	**Shall block all noises**	-	-	-	0	-		0	0
D6.01	**Only one component**	0	0	0	0	-		0	-
D6.02	**Assembly time**	0	0	0	0	-		0	0
D6.03	**Ease of assembly**	0	0	0	0	-		0	0
D7.01	**Lightweight part**	0	0	0	0	-		0	-
D7.02	**Lightweight design**	0	0	0	-	-		-	-
D8.01	**Cost per part**	0	-	0	-	-		-	-
D8.02	**Cost of manufacturing**	0	-	0	-	-		-	-
D8.03	**Material per part**	0	0	0	-	-		-	-
D9.01	**Fit in all present models**	0	0	0	0	-		0	0
D9.02	**Fit in future models**	0	0	0	0	-		0	0
Sum +		1	1	1	0	0		0	0
Sum 0		12	9	11	9	2		9	5
Sum -		1	3	1	4	11		4	8
Net Value		0	-2	0	-4	-11		-4	-8
Ranking		1	4	2	5	8		6	7
Further Development		Yes	Yes	Yes	Yes	No		Yes	Yes

Appendix A30. – Modified Morphologic matrix after first screening

Function	Solution 1	2	3	4
Remove water/Hose routing	Hose in original position 			
Reduce/change water movement, backwards	Original hose 	Hose inner structure with smaller canals 	Ribbed/bellowed inner structure of hose 	Hose with inner spiral 
Reduce/Remove pressure difference	Original drain plug 	Soft non-return valve 	Hard non-return valve 	Non-return valve which closes when pressurised 

Appendix A31. – Prototype plan

Purpose:

- Test the concept in order to confirm that it eliminates the sound phenomenon

Level of approximation:

- Exact geometries from CAD drawing
- As similar material properties as possible, if correct material is not available

Experimental plan:

- Rapid prototype / Free-Form Fabrication of one design of drain plug
    - Six samples with three different materials and two different positions of non-return valve
- Mount the drain plug in an affected car
- Conduct test drives in different speeds and at different tracks.

Schedule:

- Week 15-16 CAD drawing
- Week 16-19 Manufacturing of prototype
- Week 19-20 Mounting of drain plug and perform test drive

Appendix A32. – Kesselring concept scoring matrix

Criteria		Robustness	Design for Recycling	Shall block all noises	Only one component	Assembly time	Ease of assembly	Lightweight part	Lightweight design	Cost per part	Cost of manufacturing	Material per part	Fit in all present models	Fit in future models	Technical sum	Technical comparative number	Rank
		D2.01	D4.01	D5.01	D6.01	D6.02	D6.03	D7.01	D7.02	D8.01	D8.02	D8.03	D9.01	D9.02			
	w	8,5	2,3	4	8	9,1	9,1	8	2,8	12,5	5,7	3,4	11,9	14,8	T	T/T_{max}	
Maximum solution	v	5	5	5	5	5	5	5	5	5	5	5	5	5			
	t	42,5	11,5	20	40	45,5	45,5	40	14	62,5	28,5	17	59,5	74	500,5	1	
Soft non-return valve integrated in drain plug with lid facing upwards	v	3	5	5	5	4	4	4	4	4	4	4	3	4			
	t	25,5	11,5	20	40	36,4	36,4	32	11,2	50	22,8	13,6	35,7	59,2	394,3	0,79	2
Soft non-return valve integrated in drain plug with lid facing the side	v	3	5	5	5	4	4	4	4	4	5	4	3	4			
	t	25,5	11,5	20	40	36,4	36,4	32	11,2	50	28,5	13,6	35,7	59,2	400	0,80	1
Soft non-return valve integrated in the sunroof frame	v	3	3	4	5	5	5	4	4	3	4	4	4	3			
	t	25,5	6,9	16	40	45,5	45,5	32	11,2	37,5	22,8	13,6	47,6	44,4	388,5	0,78	3
Hard non-return valve integrated in drain plug	v	3	4	5	2	4	4	4	4	3	4	3	3	4			
	t	25,5	9,2	20	16	36,4	36,4	32	11,2	37,5	22,8	10,2	35,7	59,2	352,1	0,70	6
Hard non-return valve integrated in sunroof frame	v	3	3	4	2	5	5	4	4	3	4	3	4	3			
	t	25,5	6,9	16	16	45,5	45,5	32	11,2	37,5	22,8	10,2	47,6	44,4	361,1	0,72	5
Non-return valve in soft rubber material, closes when pressurised	v	2	5	4	5	4	4	4	4	4	5	4	3	4			
	t	17	11,5	16	40	36,4	36,4	32	11,2	50	28,5	13,6	35,7	59,2	387,5	0,77	4
Non-return valve integrated in the hose within a chamber	v	2	2	4	2	3	3	3	3	3	3	3	2	2			
	t	17	4,6	16	16	27,3	27,3	24	8,4	37,5	17,1	10,2	23,8	29,6	258,8	0,52	7
Non-return valve with small hatch connected to a spring within the tube	v	1	2	4	2	3	3	2	3	2	3	3	2	2			
	t	8,5	4,6	16	16	27,3	27,3	16	8,4	25	17,1	10,2	23,8	29,6	229,8	0,46	8

Appendix A33. - Experiment description for drainage capacity tests on the new concepts

Purpose:

To verify that the new drain plug concepts will fulfil the requirement to drain 2 litres per minute

Tools, Measuring equipment, Test facilities:

- A stopwatch
- Drain plug prototype to be evaluated
- Drain hose
- Water
- Graduated cylinder
- A fixture to mount the drain plug and hose to.

Test Parameters:

- Drain plug prototypes

Test Sequence:

- Mount a drain plug prototype
- Measure 2 litres of water in a graduated cylinder
- Pour water through the drainage system
- Clock the time it takes to drain 2 litres of water

Requirements:

The drainage time must be measured to shorter than 1 minute per 2 litres of water

Appendix A34. – Drawing of final concept