Division of Machine Design

Optimization of front wheel arch liner

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Preface

This report is written as a part of the course TMXD20, master thesis at Volvo Cars, and there are a large number of people who have helped us and we would like to send our special thanks to. The work has constantly gone smoothly forward and that, in many cases thanks to all people we have worked with.

Our tutor from Linköpings Institute of Technology, junior lecturer Kenneth Bringzén, has helped and guided us through the work in a most satisfying way. Kenneth is an inexhaustible source of ideas and questions regarding the master thesis have never grown into problems thanks to him.

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We have been located at Volvo Cars in Gothenburg, department 93641 under the entire project. We would like to send our special thanks to the entire department 93641 and especially to manager Erik Rydberg, design leader Beatrice Jonsson, design leader Christian Rosborg and design engineer Robert Freidlitz. We have enjoyed working as a part of the group and it is with out a doubt a very good place of work.

At Volvo Technology Corporation we send our special thanks to the information specialists Helena Mankell, Jonas Kanold and Birgitta Arnell. They made our benchmarking possible in an effective and comfortable way. The help we got here gave us a truly good start on our master thesis.

Most of the photos are taken by Martin Alfredsson (Benchmark, Attributes and cost) and Rune Ottosson at the same department helped us a lot when ever we needed to use the workshop. For example when we made the test wheel arch liners for contamination test 3. He also ordered the wheel arch liners that we used as test sample materials. We send our special thanks to Martin and Rune.

At the department Material Centre we would like to send our special thanks to Kristina Hedbom who has helped us with almost every test that we have performed. She has always helped and supported us in a mostly considerate way even if she has been busy. Textile engineer Hengameh Monfared, helped us and was not at least a very good company during the mostly boring wear resistance test. Test engineer Arbi Nageye helped us with the stiffness test. Thanks to all of you.

Vehicle engineer Lars Kjellgren has made it possible for us to easily reserve and borrow cars which we have used, mainly for contamination test 3. We would like to thank Lars for his work.

Due to the fact that we did not perform tests of splash shields on our own, the help with material and knowledge from earlier tests that we got from attribute leader contamination, Joakim Larsson and Emil Cerdier, have been very useful. Thank you very much.

At the department Noise and Vibration Center, Bo Karlsson and Mikael Norgren have helped us with both knowledge and equipment. Most valuable help for us in this project which we are very grateful for. We would like to send our thanks to Bo and Mikael.

At Chalmers University of Technology we would like to thank Börje Wijk. He helped us with the very important noise absorption test which we were not able to perform at Volvo Cars.

Kjell Johansson, task leader 93642, has helped us with many things but especially with Catia V5 and computer problems. He has also been a good desk mate to talk away some time with. Thank you for a pleasant time and all help.

To sum up we can say that our master thesis have been great fun not at least thanks to all whom we have worked with or just socialized with. We have established valuable contacts and met many new friends which we hopefully will have the chance to see again. We will without a doubt look back at this time with pleasure and see it as a perfect end of our time as students.

Linköping, February 3, 2006

Hans Pettersen Martin Torstensson

Abstract

About ten years ago Volvo Cars could see that car manufactures began to introduce rear wheel arch liners made of non-woven fabrics or some kind of laminate which are mostly common today. Volvo Cars have also seen that competitors now are beginning to develop the front wheel arch liners more and more and expect a development equal to the one for the rear wheel arch liners. This is why we are set to optimize the front wheel arch liner.

For development of mechanical products such as car parts, a discursive method is most suitable to follow. For example systematical concept development which we have used in our work.

From a technical point of view, our results shows that the penta laminate used for the wheel arch liner on Mercedes Benz S-class is by far the best material. Unfortunately it is rather expensive which of course affects its result in a negative way when cost is taken in to consideration. When including cost, the solid plastic is actually rather economical. After assessment of the result in total we are however convinced that Volvo Cars should concentrate on further research of penta laminate and open negotiations with different suppliers regarding a material of this kind.

Regarding the geometry, the tests and studies that Volvo Cars have performed earlier on splash shields clearly shows the usage of the part and further research done by our selves does not point at any problems with a splash shield integrated in the wheel arch liner.

Keywords: Volvo Cars, wheel arch liner, laminate

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1 Introduction

Every car industry is under constant development because of the competition between different brands but mostly because of the constant rising demands from customers. A new car always has to present the state of the art in every aspect. This also includes a part such as the wheel arch liners which is why our task at Volvo Cars, is to optimize it.

1.1 Background

In over 75 years of existence, Volvo has become one of the best known car brands in the world. It certainly belongs to the premium segment and the cars are sold all over the globe. Of the 60.3 million or so cars sold worldwide in 2004, about 456,000 were Volvos and about 27,575 people were employed by Volvo Cars at the end of 2004, the great majority (19,681) in Sweden. Three core values affects Volvos operations, products and actions more then anything else and have done so from the very beginning of the company's activity. These core values are safety, quality and environment. Volvo has for a long time been a leader in the area of safety and strongly attends to remain so. When it comes to quality, it is not only a matter of high quality products. Volvo aims at keeping a high quality level through the entire product chain, from manufacture to sales and aftermarket service. Another aim is to be ranked as an environmental leader in the premium segment of the car industry. New engines, cars, processes etcetera constantly contribute to more environmentally friendly products.

Since 1999, Volvo Cars has been a wholly owned subsidiary of Ford Motor Company, one of the absolute biggest carmakers in the world. Together with Jaguar, Land Rover and Aston Martin, Volvo is a part of the Premier Automotive Group (PAG), Ford's premium car division. Volvo Cars is a 'Centre of Excellence for Safety' for Ford Motor Company, as well as a 'Centre of Excellence for Telematics' for PAG.

Not very well known but still important parts of a Volvo, are the wheel arch liners and the splash shields. The parts serve on the one hand for reduction of the transmission into the vehicle interior of the running noises generated during traveling of the vehicle trough the wheel rotating on a surface. On the other hand the parts serve as spray protection against particles highly accelerated during travel, due to the rotating wheel, such as sand or gravel, and for protection against water or mud. Wheel arch liners and splash shields also bring about, in their function as spray protection, for example a protection of the bodywork or of the engine bay from paintwork damage or corrosion and from contamination by highly accelerated particles and/or water or mud. Further, the parts also serve as covering over openings, such as for example ventilation openings, which in the rearward side region of the vehicle open into the vehicle bumpers.

1.1.1 Problem statement

Due to all tasks the wheel arch liners and splash shields are suppose to solve, the demands are very high. Not only on its capabilities but also on its characteristics. These parts must for example have high sound absorption coefficient and be resistant to water and dust. Also, with regard to the constantly increasing efforts of the automobile industry to reduce component and vehicle weights, in particularly with regard to the generally demanded reduction of the average fuel usage of the vehicles, the high weights of these parts are increasingly less accepted. About ten years ago Volvo Cars could see that car manufactures began to introduce rear wheel arch liners made of non-woven fabrics or some kind of laminate which are mostly common today. Volvo Cars have also seen that competitors now are beginning to develop the front wheel arch liners more and more and expect a development similar to the one for the rear wheel arch liners. There are several examples of front wheel arch liners manufactured in non-woven fabrics or some kind of laminate already. This is why it is crucial to find an optimized solution with the right geometry, material and manufacturing for Volvo Cars.

1.2 Scope

Volvo Cars have developed the rear wheel arch liner with included parts very far because of its great influence on the environment in the passenger compartment, but the efforts in optimizing the parts in the front wheel arch liner, have not been as great. It is now our task to do so with a few exceptions. Finding the most suitable material and investigate the possibility to integrate the splash shield in the wheel arch liner has the highest priority. Another big issue that we will have to leave out is the edge with its fixation points, in contact with the fender.

2 Purpose and Research Questions

The purpose with the master thesis is to optimize the front wheel arch liner regarding material, geometry and cost. The weight of the wheel arch liner and the noise inside the passenger compartment, are to be reduced considerably. It is also of great importance to investigate the possibility to integrate the splash shield in the wheel arch liner to decrease the costs and simplify the assembly. Important questions which we carefully have to answer are; which is the most suitable material for this purpose? Solid plastic of some kind, solid non-woven fabric or a laminate? Regarding the geometry; which is the most suitable design? One or several parts? With or without components in other materials? With or without integrated splash shield?

We intend to carry out several tests whose purpose is to indicate clear results for us to evaluate. Our evaluation will later on serve as a recommendation for Volvo Cars.

We are in the first place working towards a specific project but the outcome of our report may also be used in future projects.

3 Theoretical Frame of Reference

3.1 Article and patent search

The project starts with benchmarking, to see what other automotive companies are producing and to see what is coming in the future. One way to do this research is to search articles and patent in different databases. Volvo Cars have together with Volvo Group their own library which we have used in this case. The easiest way to search is to contact the library staff and ask for help because of the complexity of the systems. We came in contact with Helena Mankell and Jonas Kanold, information Specialists at Volvo Technology Corporation. Helena Mankell searched for articles and Jonas Kanold searched for patents. Databases used for article search were:

- Compendex
- Mechanical and Transport engineer abstract
- Pira
- Rapra
- Chemical abstract
- Global mobility (SAE)

Databases used for patent search were:

- Derwent World Patent Index
- Delphion
- Espacenet

To be able to sift through all material Helena Mankell and Jonas Kanold were asked to search for certain keywords, for example:

- Wheel arch liners
- Wheel house liners
- Wheel house shell
- Wheel well liners
- Noise
- Textile
- Absorption

The article search gave only a few matching articles but the patent search was luckier. There were several patents of great interest for our project and many of them were about different types of laminates. For example different types of material layers and different structures.

Of all articles and patents, we have studied and analyzed a great deal but we have chosen to present only summaries of the most interesting ones in the report. The chosen articles and patents show the large differences that can occur between wheel arch liners from different producers.

3.1.1 Application of textile and polymeric surfaces for acoustic properties

Journal of the Textile Association, No. 4 2004

Noise pollution is becoming a serious health risk not only to the workers working in noisy surroundings but also to the urban inhabitants of industrialized cities and towns. The exposure to the noise of vehicular machines has worsened the situation.

The use of textile for noise reduction is based on two major advantages of these materials, low production costs and small specific gravity.

Studies have been performed of various non-woven fabrics of natural as well as synthetic fibers for their capacity to absorb sound with respect to various frequencies as well as distance from the sound source. The results clearly indicate that noise absorption capacity is also a function of various physical characteristics of non-woven fabrics like thickness, air permeability, fiber content, porosity and weight of the fabric. The degree of porosity, the thickness of the layer and frictional resistance to flow through the pores, will all affect the actual value of sound absorption. Lowest absorbance by plain surface confirms that rough surface texture can absorb more sound than plain one. The level of sound absorption in general varies depending upon nature of fiber, porosity and also the number of layers. It is also a function of thickness and frequency as well as distance. For any given substrate, at a fixed thickness, level of sound absorption certainly depends upon the texture of the surface as well.

3.1.2 Reduction in weight in acoustically active components taking the example of the rear wheel liner of the Audi A6

Plastics in Automotive Engineering: Designing the Future, Mars 1999

3.1.2.1 Main methods of reducing noise

There is a number of simple ways of reducing the noise inside the passenger compartment which is caused by the tire noise:

- drive slowly
- drive over an ideally smooth road surface
- fit the vehicle with narrow tires of large diameter

However it is not the job of the automobile developer to optimize road surfaces or to educate the customer. Tire width and diameter are in part determined by technical factors but are very frequently also associated with aesthetic preferences on the part of the vehicle owner. What this leaves us with from the technical point of view are passive noise control measures – in other words, fitting insulating and muffling materials in the wheel well area.

Resonance absorbers

One approach to weight reduction is to implement sound absorption via panel, sheet or Helmholtz resonators. With sheet resonators the resonating mass is a sheet which is impermeable to air. The recovery forces arise from the resilient of the air in the cavity of the resonator. Attenuation is achieved by porous materials (for example, open celled foams) affixed to the walls of the cavity. A correct setting for the attenuation is just as important as the choice of natural frequency f_0. If there is dirt stuck on the surface of the sheet, this can change the natural frequency in undesired ways.

Insulation

If the air is full of hard and incompressible water droplets, such as is found during travel in the rain, and these droplets are given a high kinetic energy due to the rotation of the tires, it will be best to use lightweight soft materials for sound insulation. They will break a water droplet with maximum gentleness.

Attenuation

Airborne sound attenuation is the absorption of the sound by conversion of the sound energy into heat. Materials which absorb sound are referred to as sound absorbing materials. Their behavior is ideal when a sound wave is able to penetrate them without resistance, in other words, without any reflection.

In its open-pored structure the velocity is reduced – that is, the kinetic energy is transformed into heat. It is most effective where the acoustic velocity v is at its maximum. In the case of a standing wave in front of an acoustically hard wall, the ideal distance of the absorber material from the wall is $\lambda/4$.

Thin coatings on an acoustically hard wall have very little effect since the movements of the molecules in those are virtually at zero.

3.1.2.2 State of the art – analysis of the competitive situation

Before starting on a new development at Audi an analysis of the competitive situation is usually carried out. It revealed, with one exception, conventional noise control measures in the well:

- Sprayed-on underbody sealing (PVC, bitumen, wax)
- Wheel well liners made of polyolefins
- Wheel well liners made of barites-filled polyolefins

The components were thermoformed or injected with wall thicknesses between 1 and 3 mm. The sole exception was the rear wheel well of a compact car which was furnished with a strip of non-woven polyester fabric directly above the tire.

The main reason for using wheel well liners at the rear axle is the noise of spraying water created when driving on a wet road surface.

A comparative measurement creating solid-borne sound by means of a water jet on the test rig indicated that there were considerable advantages in such a material although the area weight was 65% less than of PP wheel well liner filled with barites.

3.1.2.3 Laboratory tests of needle felts

- Water absorption: very high (=63 % wt.)
- Acoustics: OK, marked water absorption leads to further reduction of the interior noise level.
- Cleaning characteristics: Not OK. High-pressure cleaner buckles the wheel housing panel.

3.1.2.4 Optimization measures

Step by step measures were now taken aimed at improving the functional properties.

- The increase in rigidity causes a deterioration in acoustic properties
- The modified binder means an increase in costs
- The greater quantity of binder leads to an increase in mass and cost
- The compressed matrix means a thinner component

Table 1 Optimization measures

Problem	Action
Warpage and after shrinkage at high temperatures	Optimize fiber binder
Inadequate stability of shape	Increase part rigidity by: • Beading and stiffener ribs • Increase modulus of elasticity by greater proportion of binder
Penetration of dirt particles, Poor cleaning qualities	Make matrix denser by: • Higher proportion of binder • Shorter polyester fibers
Water permeability	Change over to flat needle fleece

Use of shorter polyester fibers makes a reduction in costs possible.

Due to lack of thermal stability in the fiber-binder composite, at high ambient temperatures there occurred changes in shape and marked shrinkage of the wheel well liners. The consequence was that the wheel well liner no longer lay against the side panel frame, the outer edge became visible and free access to the tire was no longer assured. The shrinkage rate varied locally from 1.5 to 2%. Thermal stabilization of the latex binder up to 100 °C meant that the after shrinkage could be forced down to less than 0.5%.

It was necessary to increase the inherent rigidity and strength since the wheel well liner had to lie with preloading against the bodywork so that it could perform its sealing function. In addition, it had to be ensured that no impermissible elastic deformations or buckling occurred during marked build-up of mud or ice, even when driving over potholes.

- Provision of beadings and stiffener ribs meant that the required load-bearing capacity could be obtained in most parts.
- In the area of the wheel well externally, the restricted access to the tire meant that the only way to increase rigidity was by increasing the proportion of binder. Only the fleece layer impregnated with binder determines the rigidity.

If the fibers are almost completely impregnated with binder, this will impair the acoustic properties to a point that using an expensive Dilour fleece no longer makes sense (Figure 1). For this reason an inexpensive flat needle fleece was used instead. In this way the additional costs of binder modification and for greater quantity of binder could be balanced out.

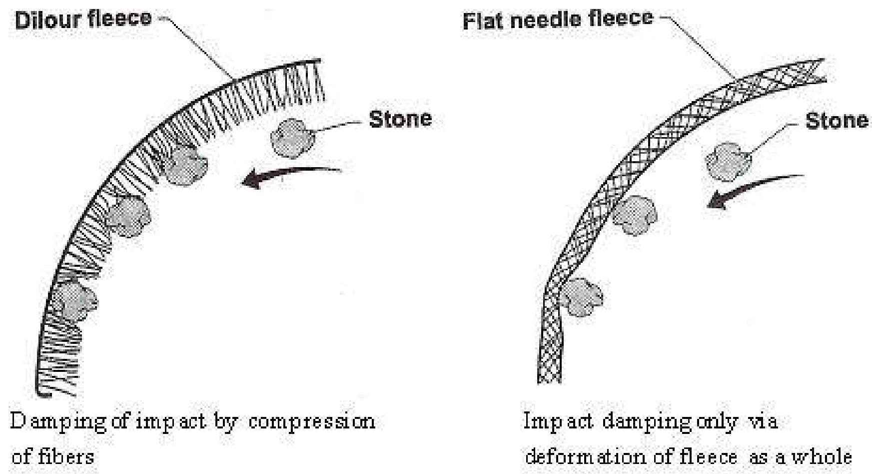


Figure 1 Particle impact on Dilour and flat needle fleece

3.1.2.5 Optimization of contamination properties

The dirt take-up of the non-woven fleece is a leading point of weakness in comparison to injection moulded wheel well liners. Coating the fleece with a thin sheet of water – impermeable polyethylene before reshaping it improves the contamination properties of the wheel well liner. For reasons of wear and acoustic properties, this sheet must not be applied to the side facing the wheel (Figure 2). In the area between the wheel well liner and the bodywork the protective function naturally will be less effective but use of a Dilour fleece makes complete sense since the filtering effect of the fleece is reduced and more dirt can be washed out again by the spray water. Without this sheet of polyethylene, part of the water would run down at the body side on the wheel well liner while leaving the dirt still in the fabric.

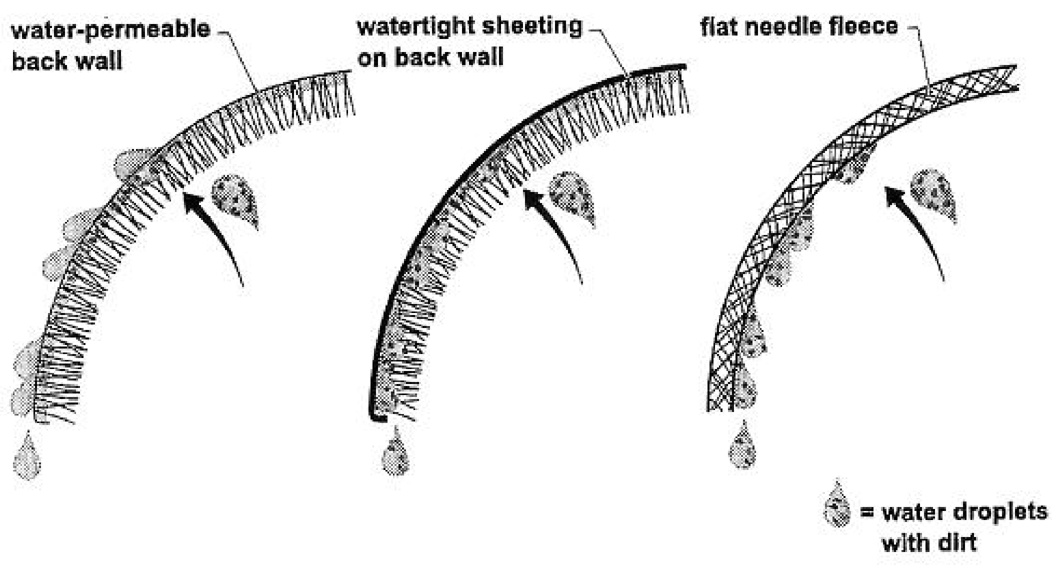


Figure 2 Filter mechanism of the non-woven fleece wheel well liner with and without sheeting

With broad-meshed fabrics very small particles (dust) cannot find any purchase. During comparative testing with dust, the non-woven fleece wheel liner is actually advantageous. It remains black and clean.

3.1.3 Wheel-to-wheel carpeting

Machine Design, No. 12, 17th June 1999

Italian automotive OEM San Valeriano SpA has developed carpeted wheel arch liners as direct replacements for the hard plastic liners now used in some models. Though plastic liners reduce auto-body corrosion, they also function as echo chambers for noise, says SV Business Development Manager Bruno Cerrato. Carpeted liners muffle such sounds and work equally well to minimize corrosion, he claims. The carpet liners also weight less. Their expected life on a car is about 10 years even in severe environments.

There have been several attempts to field carpeted arch liners in the past. But they all used existing carpeting technology that either wore out quickly from debris flying off the tires, or absorbed water. It took the development of a special material to make the concept practical, says SV. This material is a tri laminate consisting of a polypropylene middle layer sandwiched between two outer layers of needle-punched felt.
The pile of the fabric on the wheel side is perpendicular to the surface, giving it high resistance to abrasion and water. The fibers are more elastic than in regular felt, explains SV. This helps the material shed water and makes it less dense, so it absorbs proportionately more noise. The polypropylene sheet in the middle of the material provides waterproofing and consists of 60 % recycled material.

3.1.4 Multilayer molded element

Pub. No. US 2003/0011183 A1, 16th January 2003

Molded elements of this type are utilized in order to protect the automobile body from whirled-up stones as well as spray water and in order to diminish the noise level in the interior of the vehicle and on the outside the vehicle.

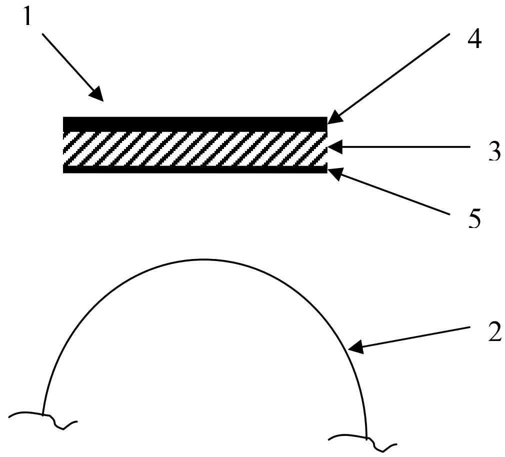
When driving on gravel-paved streets and on wet roadways, stones and/or droplets of water are carried along by the tires and propelled at high speed against the vehicle body.

The layered construction comprises a dual layer, made of a layer of fibrous material and a plastic fiber layer.

The present invention is based on the object of designing a molded element of the initially mentioned type in such manner that there is improved air-borne noise absorption and minimized excitation of solid-borne sound.

In Figure 3 and Figure 4 the relatively thick elastic layer, enclosed by cover layers 4 and 5 is designated with 3. Layer 4, respectively located on the side facing the vehicle, is a sufficiently heavy thermoplastic or duroplastic cover layer (made for example of polypropylene film or resin-coated PES fabric) which contributes not only the sealing function but also mechanical stability to the structural element 1 and which serves as a base for assembly.

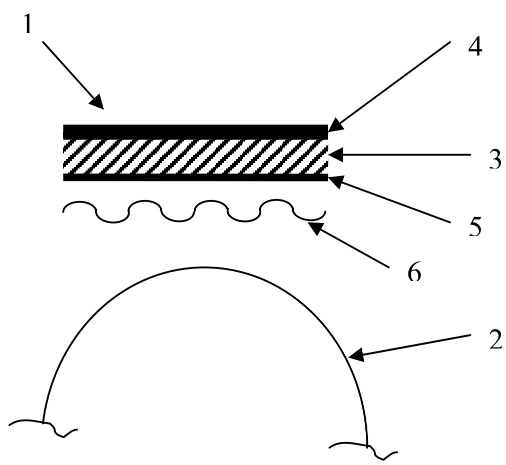
In the embodiment according to Figure 3, layer 5 is provided on the wheel side. This involves, for example, a film made of thermo- or duro-plastic material, whose essential function is to absorb and distribute the impact energy. Local deflections in the film are spring-cushioned and attenuated by the inner elastic layer 3. In addition, this said foil forms protection for the inner layer 3 and increases dimensional stability as well as stability of the whole construction.



1. Multi-layer textile wheel house shell
2. Wheel
3. Thick embedded non-woven layer
4. Cover layer
5. Cover layer

Figure 3 Material description of multilayer molded element

In the embodiment according to Figure 4, layer 5 is covered on the side facing the wheel; it is covered with a relatively thin polyester fabric. Said layer 6 already exercises a braking effect on stones, water droplets etc., so that layer 5 needs to only absorb the remaining impact energy and distribute the same over the elastic layer.



1. Multi-layer textile wheel house shell
2. Wheel
3. Thick embedded non-woven layer
4. Cover layer
5. Cover layer
6. Thin layer of polyester fabric

Figure 4 Material description of multilayer molded element

3.1.5 Wheel house shell for a vehicle and method of making same

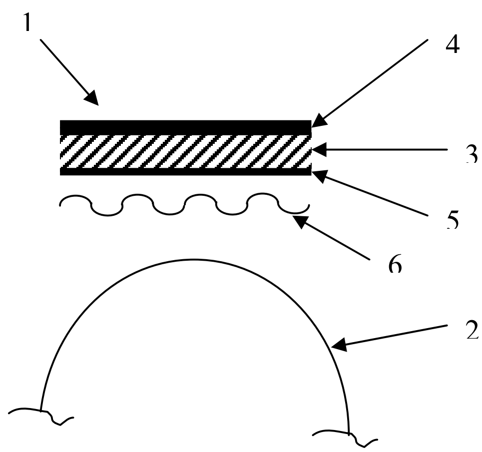
Pub. No. US 2003/0220034 A, 27th November 2003
This patent is a further development of the patent US 2003/0011183 named above.

A wheel house shell for a vehicle has a multilayer textile construction, in which case a covering layer is provided on the side of the wheel house shell facing the wheel. In order to avoid absorption of water and dirt respectively by the covering layer, the latter is produced of a hydrophobic weave or knit made of PTFE (Teflon) fibers. See Figure 5.

The invention relates to a wheel house shell for a vehicle, which has a multi-layer textile construction, a covering layer being provided on the side of the wheel house shell facing the wheel.

Wheel house shells of the initially mentioned type have positive acoustic and mechanical characteristics, whereby splashing water noises and stone throw noises are reduced. Furthermore, as a result of the textile construction, the weight is reduced. In the case of this arrangement, the covering layer facing the wheel is formed by polyester non-woven. It is disadvantage of this wheel house shell that, on one hand, the polyester non-woven absorbs a considerable amount of water and that, on the other hand, dirt adheres particularly well to the relatively rough surface of the polyester non-woven. Cleaned by means of a high-pressure cleaning device, the water absorbed by the covering layer of the wheel house shell will drip off for some time, which may result in undesirable puddles under the vehicle.

It is an object of the invention to further develop a textile wheel house shell of the initially mentioned type such that absorption of water and dirt by way of the covering layer situated closest to the wheel is avoided.



1. Multi-layer textile wheel house shell
2. Wheel
3. Thick embedded non-woven layer
4. Surrounding layer
5. Surrounding layer
6. A hydrophobic weave or knit of PTFE fibers (Polytetrafluor ethylene fibers), Teflon by DuPont.

Figure 5 Material description of wheel house shell for a vehicle

- bonding the hydrophobic covering layer with the wheel house shell with a thermoplastic bonding agent
- mechanically fixing the hydrophobic layer to the wheel house shell by needle bonding

3.1.6 Wheel-arch cover panel for a motor vehicle

Patent. No. US 6.086.104, 11th July 2000

The present invention related to a wheel-arch cover panel for fitting on the external bodywork of a motor vehicle.

As a result of studies directed towards reducing the noisiness of the vehicle, it has been found that wheel-arch cover panels help considerably in the reduction of the noise level reached by the motor vehicle in motion. In this connection, panels formed of an impregnated, non-woven fabric reduce the noise level, but these panels are subject to rapid wear and do not achieve good water proofing. To prevent the problems encountered in the prior art, the subject of the present invention is a wheel-arch cover panel for a motor vehicle, characterized in that it is formed by a thermoformed laminar structure comprising a layer of plastics material impermeable to liquids, and at least one layer of fabric, particularly non-woven fabric, which is applied to the face of the layer of plastics material facing towards the wheel of the motor vehicle and at least a third layer which is applied to the face of the sheet of impermeable plastics material facing towards the bodywork of the motor vehicle constituted by an expanded plastics material.

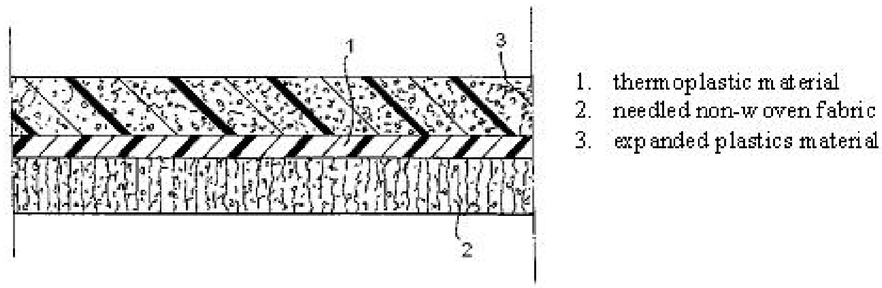


Figure 6 Material description of wheel-arch cover panel for a motor vehicle

According to the invention, the panel is formed by a laminar structure comprising a layer 1 of thermo formable, thermoplastic plastics material which can confer the necessary rigidity and impermeability to liquids on the structure. The layer 1 has a thickness of from 0.5 to 3 mm.

A sheet 2 of fabric, particularly constituted by a needled non-woven fabric, is applied to the face of the layer 1 facing towards the wheel of the motor vehicle. The layer 2 has a thickness of from 1 to 5 mm.

It has been found that non-woven fabrics having a three-dimensional structure of the type of layer 2 have optimal sound-deadening properties for the specific application and substantially reduce the level of noise generated by the wheel-arch cover panel when the motor vehicle is in motion.

In the preferred embodiment, the wheel-arch cover panel is a three-layered structure comprising a further layer 3 which is applied to the face of the layer of impermeable plastics material facing towards the bodywork of the motor vehicle. The layer 3 is preferably a layer of expanded plastics material, such as, for example, open-cell flexible polyurethane with a thickness of from 3 to 10 mm, more preferably having a surface skin on its face facing the bodywork.

The advantages of the panel of the invention lie mainly in the achievement of good sound-deadening and waterproofness characteristics as well as resistance to wear and abrasion when the motor vehicle is in motion.

3.1.7 Wheel-housing shell

Patent. No. 5.280.960, 25th January 1994

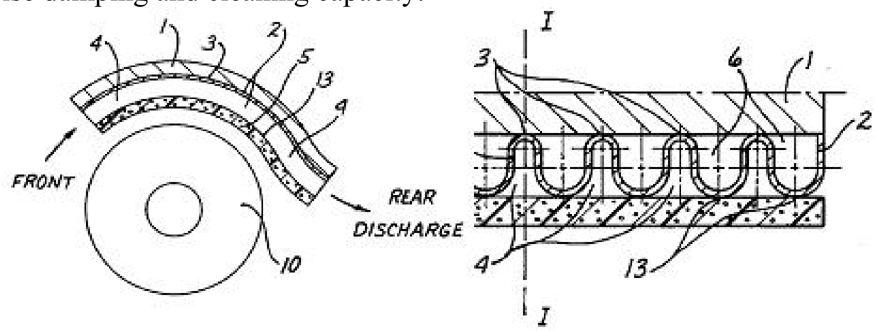
The present invention relates to a wheel-housing shell for incorporation in mudguards of a motor vehicle, which extends at least approximately parallel to the mudguard over a considerable part of the inner periphery of the mudguard and which forms with this a hose like channel having an air inlet at its end at the front in the driving direction and at its end an air outlet directed towards the roadway, the wheel-housing shell being equipped with orifices which assist or make easier the passage of water splashes into the channel.

In wheel-housing shells of the above described type, an air flow from their front end to the rear end is generated during motoring. At the same time, a vacuum occurs in the channel, and this draws the water splashes which occurs through the orifices in the wheel-housing shell into the channel and diverts them towards the roadway by means of the air flow. This prevents the water splashes from escaping from the mudguard laterally and therefore also the particular vehicle or other road users from being soiled and/or impeded.

The air flow between roadway and vehicle floor thus generates a vacuum in the channel between mudguard and wheel-housing shell, so that this space remains dry and clean and corrosion of the mudguard is therefore counteracted.

Since the filter mat dries out continuously because of the air flow from the side of the channel, the absorbed water is drawn thought the porosity in this region of the filter mat.

A web material on a plastic base is particularly suitable as a material for the filter mat. This material has the advantage of a high corrosion resistance, good process ability and a high noise damping and cleaning capacity.



1. Mudguard
2. wheel-housing shell, corrugated material
3. corrugation points
4. The channels
5. Filter mat
6. The channels

Figure 7 Material description of wheel-housing shell

3.2 Geometry theory

In this chapter we will discuss what we can do concerning the geometry of the wheel arch liner to prevent water and dust from reaching in to the engine bay. To make the wheel arch liners easy to assemble even if the splash shield is integrated. The wheel arch liners that are used today are made in PP, polypropylene. The biggest reason for this is that it is cheap and has high stiffness. But PP has a high density, the one we have used in our tests has a density of 0.93 g/m^3 compared with laminate between 0.26-0.44 g/m^3 respectively between 0.26-0.28 g/m^3 for non-woven fabrics. If we change to laminate or non-woven fabrics we will reduce the weight of the wheel arch liner used today. As a result of the weight lost we will be able to increase the area of the wheel arch liner and integrate the splash shield and still have a lower weight than today. To see if other automotive companies have integrated the splash shield or some thing else with the same effect and how they solved it, we looked at many competitors cars. There were not many that had an integrated splash shield, the ones we saw were Audi A3 and Peugeot 406. To see if it is possible to integrate a splash shield and to increase the area of the wheel arch liner around moving/rotating parts is what this chapter is about.

Figure 8 Splash shield integrated in the wheel arch liner, Audi A3 respectively Peugeot 406

3.2.1 Problem

Some problems yet not solved in the wheel arch liner could possibly be solved by a carefully designed wheel arch liner. The solutions are however not obvious because of the complexity of the problems.

3.2.1.1 Splash shield

A description of the splash shield is as follows: The splash shield sits in the front wheel arch liner as shown in Figure 9. Its task is to prevent water from reaching in to the front of the engine bay, especially the belts of the AC-compressor. In Figure 10 a Volvo XC90 with and without splash shield is presented. The splash shield is however only put in place, not assembled.

Figure 9 With splash shield, Peugeot 406, respectively without splash shield, SAAB 9-3

Figure 10 XC90 with and without splash shield

The tests of the splash shield that we have to perform to get the results we need are too expensive both concerning time and cost. Instead we consulted some people that are experts on this subject to get the information and knowledge that we need when we shall seal this area.

We consulted Joakim Larsson at contamination department. We wanted to get information on how he saw the problem with water and mud reaching the engine bay. He said that the worst place is just in the front of the wheel arch liner, it is in this area the splash shield is assembled. He suggested that we should try to seal this area. He showed us films of what happens in the engine bay and in the wheel arch liner area when driving in different speeds through water. We saw a film of a car driving through water, with a splash shield that was assembled as a separate part and another film of a car without splash shield. There was a big difference with and without a splash shield, so our idea is to try to integrate a kind of splash shield.

To get even more information about contamination we consulted Emil Cerdier test engineer contamination. He talked about the effect of using splash shield. He showed us many films were they had tested splash shield prototypes, see Figure 12. Once again we saw the positive effect of a splash shield.

3.2.1.2 Stiffness

If there will be a material change from solid PP to laminate or non-woven fabrics there will be problems with stiffness due to decreasing of Young's modulus. This should however be possible to solve with changes in geometry.

3.2.1.3 Assembly

If we only should optimize the wheel arch liner from an assembly point of view, it would be a very small wheel arch liner made of paper and only have one fixation point. This is not viable because it would not give any protection. What we want to do is for example to integrate the splash shield but still make it easy to assemble.

3.2.1.4 Contamination

From a contamination point of view, it is better to have wheel arch liners made of plastic, for example PP. As mentioned earlier we consulted Joakim Larsson, to hear what he had to say about different materials such as laminate and textile. A big disadvantage with laminates that have textile as an external layer and non-woven fabrics, is its ability to absorb water and that gravel and mud can get caught on its surface. When there is gravel and mud on the surface and the wheel arch liner is rubbing against the sub frame or body, this is just like rubbing sandpaper against metal. Add to this that the sandpaper is damp as a wet rag. It will wear the paint down and make the metal rust. This really justify the contamination tests described in chapter 4.5.5. So when a new material is chosen due to weight and sound absorption, the material should absorb water and mud as little as possible.

3.2.1.5 Moving/rotating parts

A trustmark written by Volvo Cars says that as an initial design clearance, there shall be a minimum of 15 mm static clearance and 10 mm dynamic clearance under the full range of maximum engine motion. This gives us a lot of problems because there are many moving parts in the area around the wheel arch liner. For example driveshaft, steering stay, spring, link arm and stabilizer.

3.2.1.6 Gap

A problem we have seen on many cars, Volvo cars as well as competitors' cars, is a gap between the wheel arch liner and the sub frame and/or the under-shield. This gap gives water and mud opportunity to reach in to the engine bay. As mentioned above Emil Cerdier showed us films of tests performed on cars trying to solve the problem with the gap. One way is to assemble a splash shield on the wheel arch liner. In Figure 12 a picture of a prototype splash shield is presented that they have used it in tests. Figure 13 shows how they have tried to combine the wheel arch liner and the splash shield with the under-shield using tape. This was later on used in tests. A problem to look out for here, is the relative movement between the sub frame and the rest of the car which will stress and compress the wheel arch liner.

Figure 11 Gap between wheel arch liner and the sub frame on a XC90

Figure 12 Contamination test without splash shield and with a home made splash shield

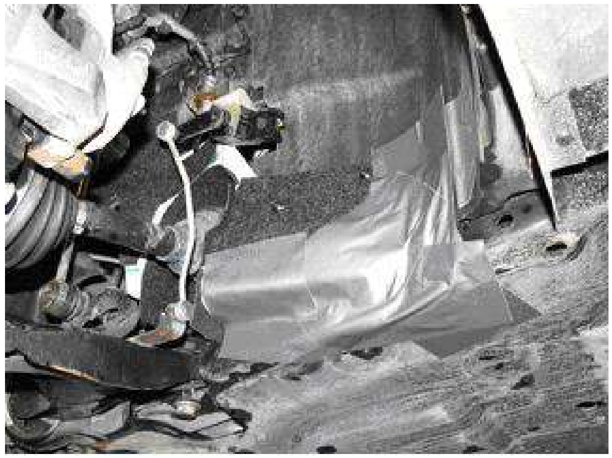


Figure 13 Contamination test with a splash shield attached to the under-shield

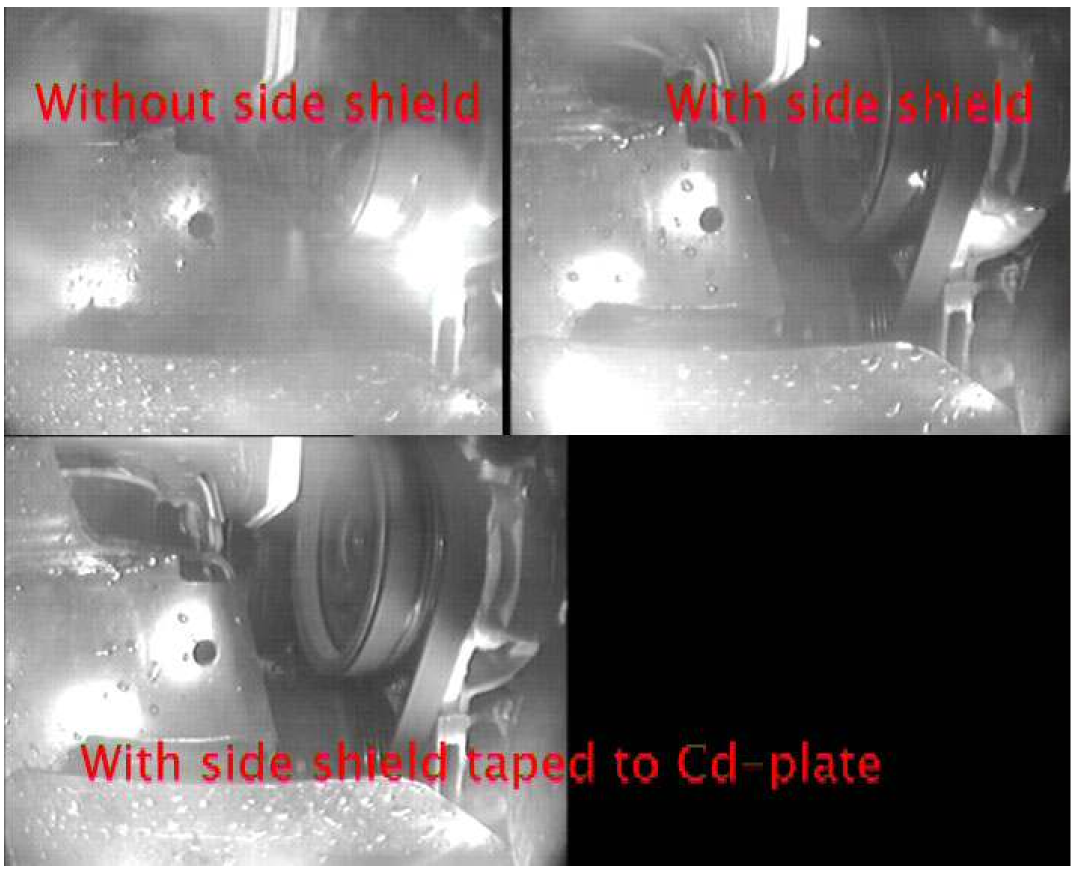


Figure 14 Test of splash shield assembled on a car driving through water at constant velocity. (The pictures are taken from a film, where the camera is placed inside the engine bay filming from the fog light towards the AC-compressor)

It might be hard to see any differences between the different tests but the first picture "without side shield" is without splash shield, like the cars manufactured today. The picture is blurred due to the water reaching in to the engine bay and transformed in to fog due to the high temperature. The second picture "with side shield" is with a type of splash shield. It is not that much fog but still there is some. The third picture "with side shield taped to Cd-plate" is with a type of splash shield that is taped to the under-shield see Figure 13. There is less fog than in the second picture. The conclusion is that the best result is received when the splash shield is assembled with the under-shield.

4 Method

To facilitate a larger project such as a master thesis it is absolutely necessary to find a method and follow it trough planning, realization and documentation. It is not always easy to find a suitable method among the existing ones but a modified method may do just as well as long as it structures the work. There are a great amount of methods but all initiative methods for example, are suitable for relatively small problems and problems easy to overview. They are by all means fast, simple and they usually support team work but they have negative sides as well. They are restricted in relation to complex problems, can feel indistinct, do not guarantee a result and are not systematic. In other words, it is not the way to go with a master thesis. Examples are:

- Brainstorming
- Brain writing
- The analogy method (find solutions in for example other technical design or in nature)
- Inversion (do the opposite)

For development of mechatronical and mechanical products such as car parts, a discursive method such as systematical concept development is most suitable to follow which is why we focus on that kind of methods.

4.1 Systematical concept development

Systematical concept development can be divided in three phases. During concept phase one, beginning with a problem, a specification or technical regulation where properties which the product shall have, are established. In concept phase two you look in to what the product shall do and generate alternative means or solution principles for this. The result is a so-called function/mean tree which in a structured way shows the functions of the product and alternative means to realize the functions. During concept phase three means are chosen from the function/mean tree and in different combinations these sub solutions generate concepts. Finally the concepts are evaluated and a number of solutions are selected for further development.

4.1.1 **Concept phase 1** From problem to technical regulation

The objective of phase one is to establish a technical regulation which indicates partly the purpose of the product but mainly the important properties that the product should fulfill. The phase is usually carried out in four steps:

1. Critical perusal
2. Investigate state of the art
3. Investigate technical and economical possibilities
4. Establish a technical regulation

4.1.1.1 Critical perusal

In the critical perusal you try to describe what the solution of the problem shall do, without saying how. Questions to be answered are:

- What is the problem?
- Who experiences the problem?
- What is the objective?
- What are the side effects to avoid?
- What limitations are there to solve the problem?

4.1.1.2 Investigate state of the art

One of the most important elements in the entire concept development is to investigate the state of the art. It has to be carefully done to find out whether for example competitors have a product similar to the one we are developing. If it is possible to get information the easy way, it should be used. It is also important to study literature on the subject, seek in patent databases, study products which solve similar problems in other areas and so on.

4.1.1.3 Investigate technical and economical possibilities

You should in an early stage of the project make a solid appraisal whether the problem is possible to solve in theory. Do not waste time on something that can not be fully completed.

4.1.1.4 Establish a technical regulation

A well-laid technical regulation makes the concept development a lot easier. It has two important functions; it gives guide lines for the concept development and it provides with absolutely necessary information to the evaluation. You should constantly check whether the technical regulation corresponds to the customer's aims and wishes. It is common that aims and wishes are changed during a long process. A good template for a technical regulation is attached as Appendix 1.

4.1.2 Concept phase 2 Function analysis

The purpose of the function analysis is to elucidate what the product shall do, bring out the functions of the product and establish a number of different means/principles to realize these functions. Also this phase is carried out in four steps:

1. Establish black-box model
2. Create technical principles
3. Establish transformation systems
4. Establish function/mean tree

4.1.2.1 Establish black-box model

The purpose with establishing a black-box is to set a main function, input and output and operand. Notify that the black-box model shall be an abstract description of the problem not depending on a specific solution.

Figure 15 Black-Box model

4.1.2.2 Create technical principles

The technical principles which the product shall be based on are usually established in three steps. Of course technical principles first have to be generated and this is one of the most important phases in the process of product development. The choice of technical principles has a tremendously large effect on the final result. To generate several suitable technical principles you should:

- Study similar products (for example competitors) on the market and investigate what principles they are based on
- Generate different principles by using various idea generating methods, for example brainstorming, the analogy method etc.
- Study similar principles not necessary used for similar products

When technical principles are generated they shall be evaluated. This is however not a matter of finding the best principle but to exclude the obvious bad ones. Have in mind:

- Obvious advantages and disadvantages
- Is the project technically viable if this principle is chosen?
- Is the project economically viable if this principle is chosen?

There are advantages and disadvantages with both new and old technique but do always remember, no matter choice of principle, do not make a construction more complicated then necessary. Finally regarding the technical principles, make sure that the right operand has been chosen for each principle. Try to think of another suitable operand. Are there several?

4.1.2.3 Establish transformation system

For each and every technical principle a transformation system shall be established which is done in two steps. First of all the transformations, which the operand is about to go through, has to be decided. In other words, establishing a technical process. Next thing to decide is whether a human, a technical system or some other system are to perform these transformations. A transformation can for example change the operands:

- Inner structure
- Outer structure
- Position
- Time (at storage)

A transformation is divided in a preparing, performing and finishing phase described in Figure 16 below.

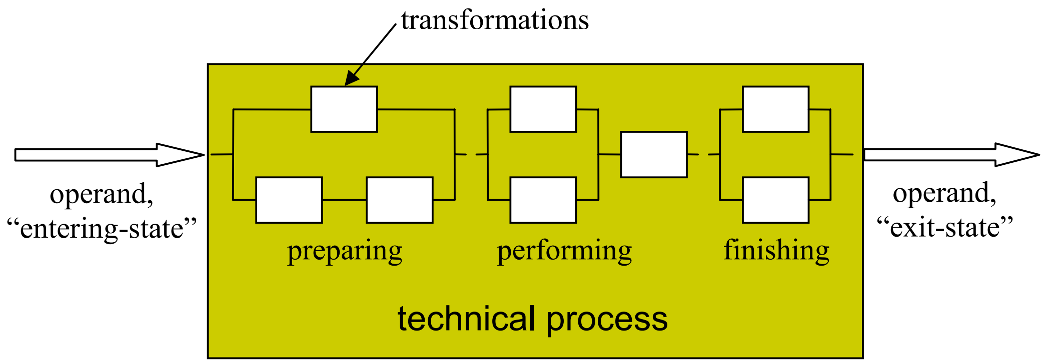


Figure 16 Technical process

Transformations may, in relation to each other, be sequential, parallel or a combination of both. After establishing the technical process, you should control whether:

- there are alternative transformations
- the order can be changed
- you should divide or put together transformations

Once the transformations are decided, it is time to define what kind of system that shall perform the transformations. Systems of interest are

- The technical system, TS (the product or system you shall develop)
- Other technical systems (For example systems constructed by others)
- The human system, HuS (a human is the operator)
- The active environment, AEnv (for example the sun can generate heat in a process)

4.1.2.4 Establish function/mean tree

Finally a most important function/mean-tree is established. The purpose is to define those functions which the technical system shall perform and come up with alternative means to realize these functions. The result is shown in a so called function/mean-tree which constitutes a detailed map over alternative solving principles and belonging sub functions.

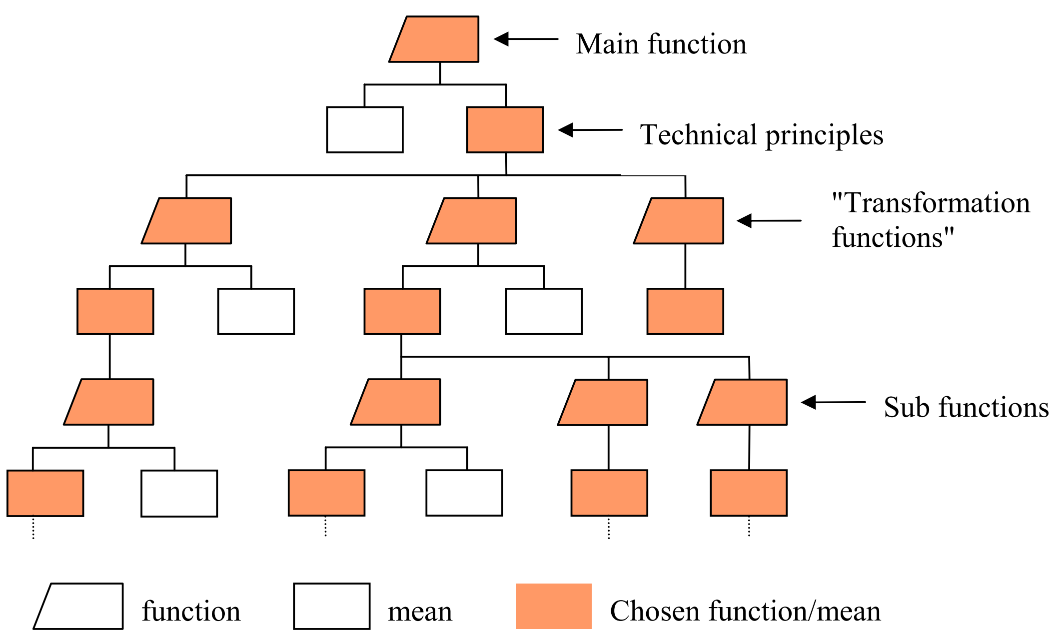


Figure 17 Function/mean tree

A disadvantage with the mean/function-tree is that it easily becomes large and hard to overview. It is therefore common to transform the men/function-tree into a morphological matrix shown in Figure 18.

Function ⇩	**Mean ⇨**				
Function 1	Mean 11	Mean 12	Mean 13	Mean 14	Mean 15
Function 2	Mean 21	Mean 22	Mean 23	Mean 24	
Function 3	Mean 31	Mean 32	Mean 33	Mean 34	

Figure 18 Morphological matrix

4.1.3 Concept phase 3 Establish concept

The purpose with concept phase three is to establish those concepts which shall constitute the foundation during the following development. The initial position is the function/mean tree or morphological matrix created in concept phase two. Concept phase three is then carried out in four steps.

1. Chose means / create concepts
2. Review and improve the concepts
3. Evaluate / chose concept
4. Correct and complement the technical regulation, plan continues work

These four steps shall thus generate a preliminary layout.

4.1.3.1 Chose means / create concepts

To create concepts is not a very difficult task. It is simply a matter of choosing different means from the function/mean-tree or morphological matrix to solve the functions. It is important not to feel finite even though the concepts shall be realistic and it is also an advantage to generate many concepts to evaluate in a later step.

4.1.3.2 Review and improve the concepts

Each concept generated in the previous step must be carefully reviewed. You should with words describe how the concepts work. Not at least to be forced as designer, to go through the concepts and realize how it actually works. A list with advantages and disadvantages regarding functionality shall be written for each concept as well as a list of future difficulties and possibilities regarding construction and production.

4.1.3.3 Evaluate / choose concept

The evaluation and choice of concept is carried out in three steps.

1. Control whether the concepts fulfills the demands according to the technical regulation. If one concept does not fulfill a demand there are two options:
    - The concept is not good enough
    - The demands are to tuff or badly formulated

   To solve the problem, either reject the concept or adjust the demand.

2. Compare the concepts to one and another by establishing a so called evaluation matrix. There are a large amount of comparison and evaluation methods which are described in a section further ahead in the report. The method shall at the concept level be rather simple due to the limited knowledge about the concepts. Important to remember is that the evaluation does not say whether the concept actually works and shall therefore only be interpreted as guidance.

3. Chose only a few concepts for further development. The choice shall partly be based on the results from the evaluation matrix and partly on the review of the concepts. Of course it is not forbidden to use common sense and "feeling" when choosing a suiting concept.

4.1.3.4 Correct and complement the technical regulation, plan continues work

For each remaining concept the technical regulation shall be corrected and complemented. Properties might be adjusted or further detailed. Other properties are added or removed. You will now receive a new technical regulation which probably is depending on a particular solution.

It is not until now a truly good plan for the project can be established. Look into recourses regarding personal, available time and financial frames. Now write a long-term plan, for example including a Gant schedule.

4.1.4 Applied method theory

Due to the fact that we are supposed to develop a wheel arch liner and not come up with an entirely new solution, neither one of the described methods are suitable to use without modifications. As mentioned above we are however looking for a form of a systematical concept development which is why we have used suitable phases described earlier and designed some phases on our own. Concept phase one is used straight off as it is while concept phase two is not usable at all in this case. This phase is mainly replaced with all our tests and already performed tests by Volvo Cars. From concept phase three we have finally used the evaluation and there chosen the weighted objectives method, described in chapter 4.2.3, to find the most suitable material. Since we only have been able to develop one solution for new geometry, this has not been evaluated towards other solutions. The reasons why we have not been able to come up with several concepts are the existing limitations in the wheel house area. There are very small possibilities for changes compared to existing solutions simply because of the lack of space.

4.2 Product evaluation

In every product development process, several concepts or solutions have to be evaluated so that the most suitable one is chosen. To be able to choose the right solution, it is of great importance to use a relevant evaluation method. Three methods are described below. The most suitable one and chosen for this project, weighted objective method, more thoroughly than the others.

4.2.1 Successive elimination

The successive elimination is based on the strategy to eliminate the bad alternatives. By systematically controlling each concept it is often easy to clear out a number of solutions. This might be useful if there is a large amount of concepts which all can not be thoroughly evaluated. Sequence of work looks as follows:

I. Identify evaluation criterions
II. Decide limits for each criterion
III. Rank the criterions after importance
IV. Asses the solutions towards the criterions
V. Alternatives which do not fulfill the limits are eliminated

The criterions may very well be of a more general character, especially at an early stage of the product development process.

- Solves the main problem
- Fulfills all demands
- Realizable
- Within the cost limits
- Safe and ergonomically
- Suits the company
- Enough information exists

Later on in the process the same method can be used but with more specified criterions.

4.2.2 The reference method

The reference method is a method where solutions are compared to each other to rank them. It does not take into consideration how much better a solution is compared to another, but only that it in fact is better. An advantage with this kind of method is that the comparison can be performed despite a finite amount of information about the alternatives. The implementation of the method can be split up in ten stages:

I. Identify evaluation criterions
II. Prepare decision matrix
III. Choose a solution as reference
IV. Compare remaining solutions with the reference solution
V. Rank the solutions based on + respective –
VI. Combine and improve solutions
VII. Choose a new reference and repeat stage I-VI. Repeat until the ranking converge
VIII. Take weights of the criterions into consideration
IX. Pick one or several solutions for further development
X. Reflect over the results

An example of a smaller decision matrix is presented in Figure 19.

Criterion	W	Alternative I	Alternative II	Alternative III
Easy to use	2	0	REFERENCE	+
Low price	4	-		0
Small spreading	5	-		-
Appearance	4	-		-
Safety	1	+		+
Reliable function	4	-		-
∑ +		1		3
∑ 0		2		4
∑ -		17		13
Net value		-16	0	-10
Rank		3	1	2
Further development?		No	Yes	No

Figure 19 Decision matrix, "+" – better, "-" – worse, "0" – equal to reference.

4.2.3 Weighted objectives method

In the weighted objective method all solutions are evaluated towards the criterions independent of each other. To be able to perform this kind of evaluation, the solutions have to be very well defined. Unlike the reference method the result from this kind of evaluation method is still valid even though solutions are eliminated or added, assumed that the criterions are the same for each solution. Also this method can be described in ten steps:

I. **Identify evaluation criterions**
The selection is similar to the one in the reference method but the criterions shall be more specific to enable quantification.

II. **Rank and weight the evaluation criterions (C_j)**
To weight the criterions a comparison in pairs is useful. An example is shown in Figure 20. It gives a fair and accurate result. In some cases an external assessment is required, for example by a customer.

Criterion	A	B	C	D	E	F	∑	$\sum_{norm}$
A (Easy to use)	-	0	0	1	2	0	3	0,10
B (Low price)	2	-	0	1	2	1	6	0,20
C (Small spreading)	2	2	-	1	2	1	8	0,27
D (Appearance)	1	1	1	-	1	1	5	0,17
E (Safety)	0	0	0	1	-	0	1	0,03
F (Reliable function)	2	1	1	1	2	-	7	0,23
						∑	30	1,00

Figure 20 Weighting of criterions. 2 – more important than, 1- equally important as, 0 – less important than.

III. Assign weight factors (λ_j) to the evaluation criterions

It is not of any importance how the weight factors look but it is the mutual relation that matters. To make them easier to understand it is however common to use one of the following examples:

- Divide $\sum\lambda_j = 1{,}00$; 100 or
- Grading: 1-5, 1-10, etc.

In the example shown in Figure 21 it is possible to use $\sum_{norm}$ as a percentage weight factor but there are cases when it might be useful or even necessary to transform such a weight factor to a grading. An example is when a criterion gets a $\sum_{norm}$ equal to zero which can be interpreted as if the criterion is highly unimportant and therefore eliminated. If the criterion however is assessed useful it can be transformed to a low grade.

Criterion	$\sum_{norm}$	Scale 1-5	Scale 1-10
A (Easy to use)	0,10	2	4
B (Low price)	0,20	4	7
C (Small spreading)	0,27	5	10
D (Appearance)	0,17	4	6
E (Safety)	0,03	1	1
F (Reliable function)	0,23	4	8

Figure 21 Weighting factors

IV. Deciding assessment scales

As described above it is possible to vary the weight factors as pleased and it is also possible to adapt the assessment scales. The steps between each grade do not have to be equally large but may very well be smaller in an interesting or critical interval. In some cases when solutions are relatively similar it can be useful to let the solutions decide the assessment scale, that is to say allow the solution which fulfills the criterion best, set the limit for the highest grade and in the same way allow the worst solution to set the lowest grade.

If a criterion is impossible to express quantitative, that is to say directly in figures, it is necessary to make a qualitative assessment. The best way to reach a good result in a qualitative assessment is to let the assumed user make the assessment. Unfortunately it is not common that these users are available at this stage in the developing process.

V. Assemble a decision matrix

As well as in the reference method it is suitable to use a matrix structure to show the assessment in. See Figure 22.

VI. Grade the solution alternatives

The grading of the solutions are made criterion by criterion so that the solutions are assessed equivalent.

VII. Determine value factor, $V(A_j)$, for each solution

The value factor $V(A_j)$ describes a solutions relation to the other solutions. The value factor is the sum of the products for respective alternatives grading and the criterions weight factor.

$$V(A_j) = \sum_{i=1}^{m} \lambda_i e_{ij}$$

By introducing an ideal concept alternative, you get a reference to the value of an optimal solution. This value can later on be used to normalize the other alternatives and above all it gives a good picture of how far an alternative is from being optimal and how large developing potential there still is.

	Alternative										
		Ideal		I		II		III		IV	
Criterion	λ	e	t	e	t	e	t	e	t	e	t
Easy to use	2	5	10	2	4	1	2	3	6	2	4
Low price	4	5	20	3	12	5	20	5	20	3	12
Small spreading	5	5	25	2	10	4	20	4	20	4	20
Appearance	4	5	20	3	12	4	16	3	12	1	4
Safety	1	5	5	4	4	2	2	3	3	4	4
Reliable function	4	5	20	2	8	4	16	1	4	3	12
V(Aj)		100		50		76		65		56	
$V(A_j)_{norm} = V/V_{max}$		**1,00**		**0,50**		**0,76**		**0,65**		**0,56**	
Ranking		-		4		1		2		3	
Decision				?		?		?		?	

Figure 22 Decision matrix. Both λ and e is graded on a scale from 1–5.

VIII. Seek week points in the solutions. Use strengths in other solutions
Study the interesting solutions and seek for week points. Are they possible to improve? Use the strengths in other solutions. If needed repeat stage V-VII for the "new" solutions.

IX. Choose solution
In the same way as in the reference method you should study and interpret both the individual assessment and the result before choosing solution. Even if the value factor $V(A_j)$ is high for a particular solution it does not have to be the most suitable solution. It might have some negative sides which have not been caught in the evaluation. Sometimes it is better to choose a more balanced solution, that is to say a solution which consistently gets good grades and do not have any truly low grades.

X. Analyze the insecurities
Many of the assessments made during the different stages are subjective, that is to say they very much depend on who has done the assessment. This may cause a certain spread of the result depending on how things are interpreted. Therefore it might be a good idea to go back and analyze the insecurities in the assessments. Especially regarding:

- Insecurity concerning values
- Insecurity concerning grading scales
- Insecurity concerning weight factors

4.3 Technical regulation

As described in chapter 4.1.1, a technical regulation must be established before it is possible to carry out any larger construction project. A well-functioning template for a technical regulation is to be found as Appendix 1. A technical regulation written for the wheel arch liner developed here is presented below. The content has partly affected what properties we want to study and test.

4.3.1 Technical regulation, front wheel arch liner

4.3.1.1 Function

What is the purpose of the product, what is the task?
Reduce transmission of running noises into the vehicle interior.
Serve as spray protection against particles highly accelerated during travel.
Protect bodywork and motor compartment from paintwork damage, corrosion and contamination.
Cover openings.

4.3.1.2 Function determining properties

What performance shall the product fulfill?
Weight: lower than 1900 g/m^2.
Temperature: withstand -30 to 95ºC.
Acoustics: noise absorption must exceed Volvo Cars' wheel arch liners used today.
Weight increase due to contamination: maximum 40 %
Weight increase due to contamination and water absorption: maximum 150 %.
Maintain properties during all weather conditions.
Maintain properties despite strong wear.

Does manufacturing, assembly, distribution or use affect size or weight of the product?
The wheel arch liner shall consist of only one part.
The geometry should admit easy and quick assembly.
The size may not exceed the limit of 15 mm from moving parts.
The wheel arch liner should not be in contact with fixed parts except at fixations.

4.3.1.3 Properties over time

In what environment will the product be used?
The wheel arch liner is intended for use during all seasons all over the world.

How often will the wheel arch liner be in use?
Daily.

Life length?
At least 10 years.

Maintenance
High pressure washing should be possible but not needed.

What parts might have to be replaced?
If any, the entire wheel arch liner.

4.3.1.4 Manufacturing properties

Shall the product be produced with existing machines/tools?
If possible, yes.

Shall the manufacturing take place at a supplier?
Yes.

Shall the product be tried out and what does that mean?
The wheel arch liner shall be tested according to Volvo Cars corporate standard. For example during Long term high speed test, Long term corrosion test and several laboratory tests.

4.3.1.5 Aesthetical properties

What demands do the customers have?
The wheel arch liner shall come into view as little as possible, both regarding geometry and color.

4.3.1.6 Law properties

What standards must the product follow?
The wheel arch liner must fulfill all Volvo Car corporate standards of current interest.

4.3.1.7 Recycling and scrap properties

Shall the product be recycled?
As much as possible.
Shall the product be separated in different materials and/or parts at scraping?
No.

4.4 Description of tested sample materials

After investigating the state of the art, a number of materials at a high technical level were chosen for our tests. All material samples have been analyzed and are briefly described below. The materials structure is described in figures showing the different layers. Non-woven fabrics mean a mixture of PET-fibers and PP-fibers. The PP-fibers melts and function as matrix. Information about thickness of the material samples can be seen as T_0 in chapter 5.2.

4.4.1 Alfa Romeo 166, rear wheel arch liner

The material has a tri laminate structure, two textile layers and one solid plastic layer. The textile layer facing the wheel is thicker than the textile layer facing the engine, see Figure 23.

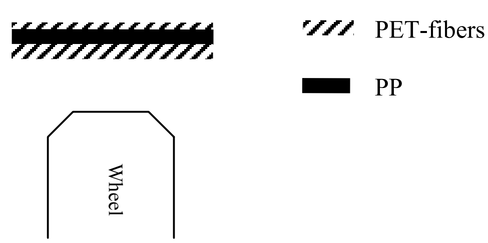


Figure 23 Material description of Alfa Romeo 166

4.4.2 Audi A6 TDI, front wheel arch liner

The material has a tetra laminate structure, two textile layers, one solid plastic layer and one expanded polymer layer, see Figure 24. The two textile layers have the same thickness.

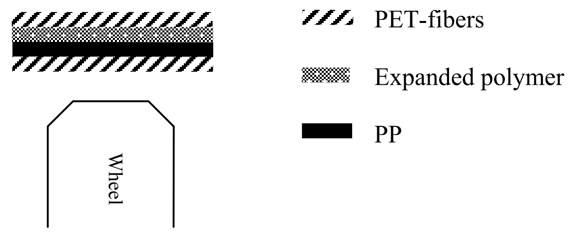


Figure 24 Material description of Audi A6 TDI

4.4.3 Audi A8, front wheel arch liner

The material has a tri laminate structure, two textile layers and one solid plastic layer. The textile layer facing the wheel is thicker than the textile layer facing the engine, see Figure 25.

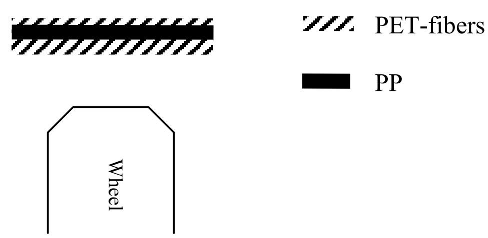


Figure 25 Material description of Audi A8

4.4.4 Maybach, rear wheel arch liner

The material has a tri laminate structure, two textile layers and one solid plastic layer. The textile layer facing the wheel is thicker than the textile layer facing the engine, see Figure 26.

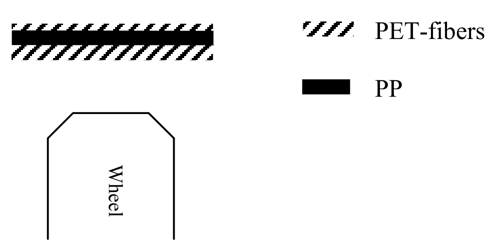


Figure 26 Material description of Maybach

4.4.5 Mercedes Benz A-class, rear wheel arch liner

The material is a mono laminate made of non-woven fabrics, see Figure 27.

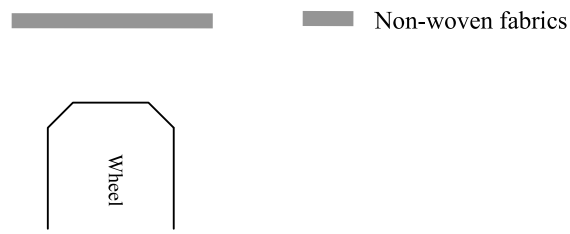


Figure 27 Material description of Mercedes A-class

4.4.6 Mercedes Benz S-class, rear wheel arch liner

The material has a penta laminate structure, two textile layers, two solid plastic layers and an insulate layer, see Figure 28. The textile layer facing the wheel is thicker than the textile layer facing the engine. The two polymer layers have the same thickness.

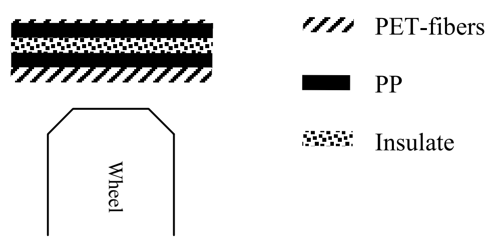


Figure 28 Material description of Mercedes S-class

4.4.7 Volvo S40/V50, front wheel arch liner

The material has a solid plastic structure, see Figure 29.

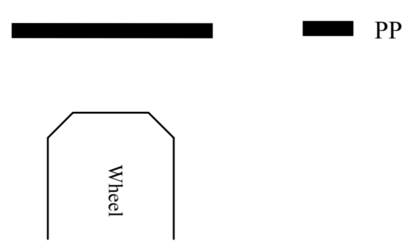


Figure 29 Material description of Volvo S40/V50

4.4.8 Volvo XC90, front wheel arch liner

The material is a mono laminate made of non-woven fabrics, see Figure 30.

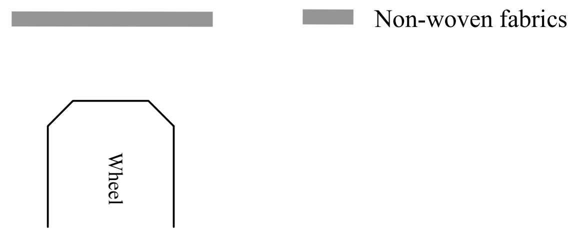


Figure 30 Material description of Volvo XC90

4.4.9 VW Touareg V5 TDI, front wheel arch liner

The material has a tri laminate structure, one textile layer, one solid plastic layer and one layer of non-woven fabrics, see Figure 31.

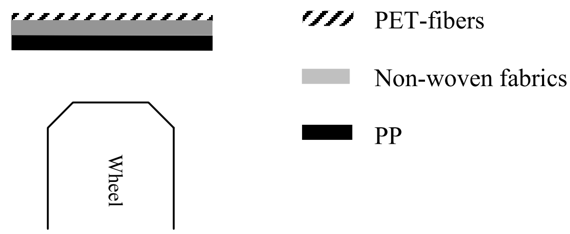


Figure 31 Material description of VW Touareg V5 TDI

4.5 Performed tests

As a part of the benchmarking and material analysis, we have carried out a number of tests in order to evaluate different competitors and materials. Since this is an activity Volvo Cars constant pursue there is a corporate standard describing a greater amount of usable tests which we have followed as far as possible. Description and implementation of each test is found below.

4.5.1 Determination of thickness and density

Because each material is taken from wheel arch liners, described in chapter 4.4, and produced by different manufactures for different cars, they all differ in thickness. To be able to carry out comparable tests we want to determine the thickness and density of each material to take into consideration. For measuring the thickness we used the corporate standard STD 1022,2311 Determination of thickness. Summarizing, the material is placed under a presser-foot which is rigged in a frame and loaded with a weight. The thickness is then read off a digital meter. The size of the presser-foot and the weight is given in the standard and decided by the type of material being tested. We decided to follow the standard given for "Felt" even though there is a category called "Non-woven fabric and other textile fabric" which in many cases would match our materials better. The reason for this is the uneven results given when using the dimensions on presser-foot and weight given for "Non-woven fabric and other textile fabric". The density is easily calculated after weight measuring and knowing the size of each material sample. All samples are punched to a size of 100 by 150 mm. It is also common to mention a weight per area unit for a certain material which is why we have calculated this as well. The results are presented in Table 3, Figure 46 and Figure 47 in chapter 5.1.

4.5.2 Wear resistance

The test is a Volvo Cars standard test described and used in a technical regulation, TR, for plastic wheel arch liner with textile insert, concerning textile area of the part. Document number 31814041. Some of the materials we have tested are not solid textile but laminate materials or solid plastic materials. To be able to evaluate the samples we need to do the same test for all materials. We found this technical regulation, named above, and after consulting Kristina Hedbom and Hengameh Monfared at Material Center we came to the conclusion that it would be the fairest test. The test was performed as follows:

- A cylindrical sample with a diameter of 110 mm was punched out from the wheel arch liners, described in chapter 4.4
- The sample was placed in the test rig, see Figure 32
- On the sample a sandpaper with grain size P40 were applied with a force of approximately 10 N (1 kg), see Figure 32
- The sample rotates with 80 rpm
- Every 100 revolutions the rotation direction was changed
- Every 500 revolutions the sandpaper was changed
- The test progressed for 5000 revolutions

The results are presented in Table 5 and Figure 48 in chapter 5.2.

Figure 32 Wear machine

4.5.3 Stiffness test

Since we have different types of material we therefore need to do the same type of test for all materials to be able to evaluate them. We found a corporate standard STD 1024, 2511. The test method is called Determination of flexural properties and is for solid plastic. After consulting with Kristina Hedbom and Arbi Nageye at Material Center we come to the conclusion that it would be the fairest test. We have picked some parts of the test and used the same equipment, see Figure 33. The experiment was performed as follows

- Test pieces were punched out from the wheel arch liners, described in chapter 4.4, five for each material. See Figure 34
- One test piece is placed on the fixture, see Figure 35
- The lower part of the fixture starts to move upwards with a speed of 1 mm/min until the sensor measures a preload of size 0.1 N

- Then the fixture moves with a speed of 5 mm/min. The sensor registers the force from the test piece. It will move 10 mm, see Figure 35
- A computer plots the force as a function of strain, for plots see Appendix 2.

The result is given in Table 7, Figure 49 and Figure 50 in chapter 5.3.

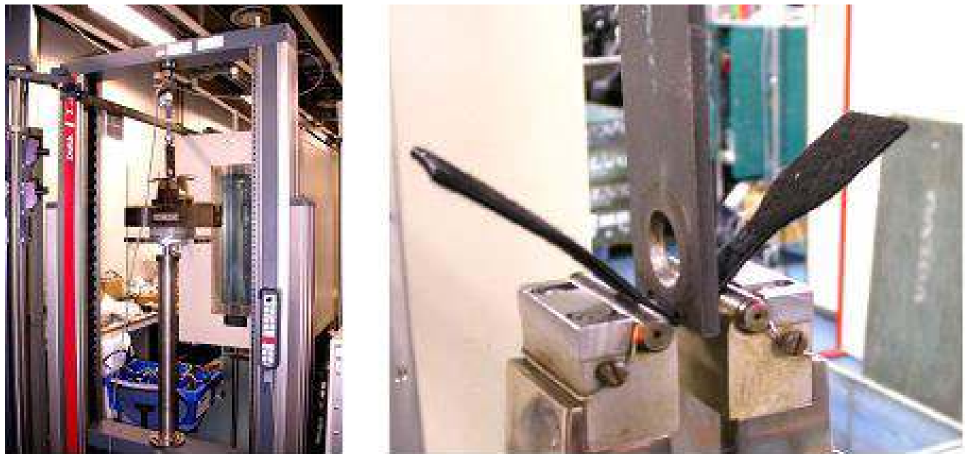


Figure 33 Test equipment for stiffness test

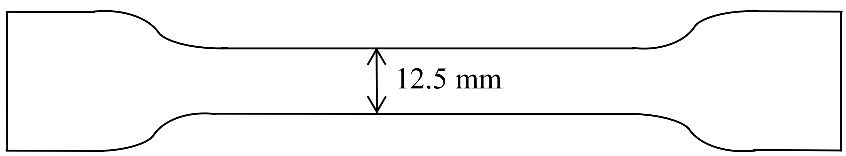


Figure 34 Test piece stiffness test

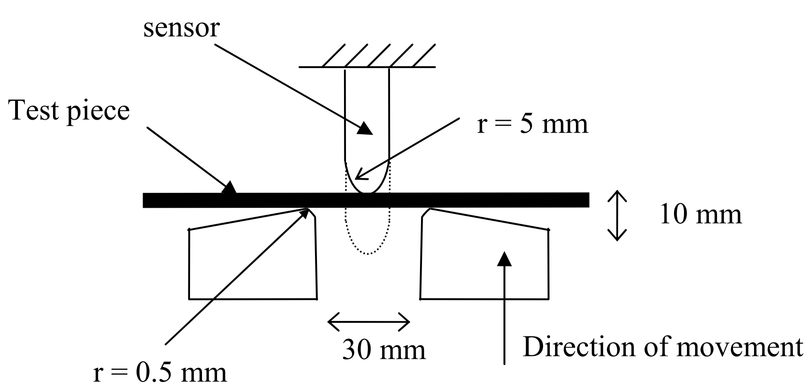


Figure 35 Geometry of the stiffness test equipment

4.5.4 Charpy test

As a continuation of the stiffness test and to see how the samples behave in cold climate we decided to do a Charpy test. The Charpy test is of corporate standard STD 1024,3516. The test is for plastics but since there are no tests for non-woven fabrics or laminate materials we decided to use it. Test principle is as follows: a test sample is placed in a vice and then a pendulum is released from a given point. The pendulum hits the sample and the machine registers the energy absorbed by the sample, see Figure 36. According to technical regulation on XC90 and XC70 with document No 31807354 respectively 31814041, the wheel arch liners, in plastic or textile, should be able to stand an impact of 5 Joule. In the Charpy test STD 1024,3516 the impact energy is of 5.5 J. Requirement: Slight permanent deformation allowed, fracture and cracks are not allowed.

4.5.4.1 Dry test
Five samples of each material were punched out and then put in a freezer. The temperature in the freezer was - 30°C. After 24 h the test was performed as described above. The reason for this test was to see what happens with the material in cold conditions. The results of the test are presented in Table 9 and Figure 51 in chapter 5.4.

4.5.4.2 “Wet" test
As in “dry test” five samples of each material were punched out. The samples were put in water for 24 h and then they were put in the same freezer of temperature -30°C after 72 h the test described above were performed. This test is a continuation of “dry test”. In this test we wanted to see what happens with the material if there is water in the material and then frozen. To see if the ice for example damages the structure in the material. The results of the test are presented in Table 10 in chapter 5.4.

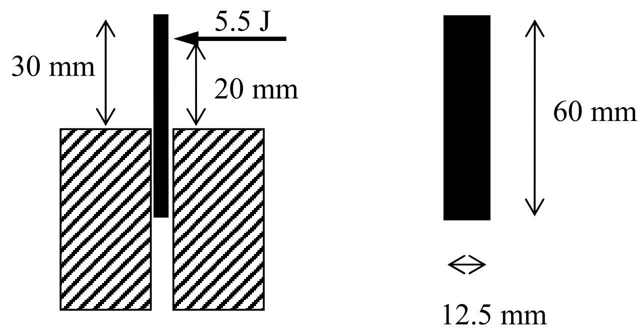


Figure 36 Test equipment and test sample

4.5.5 Contamination tests
As motivated earlier it is of great importance to keep a low weight on a wheel arch liner. But all wheel arch liners usually gain a lot of weight in wet and muddy weather conditions which is why we have performed three individual contamination tests to see just how and how much water and mud each material from Volvo and different competitors gain. These tests are however not included in Volvo Cars corporate standard but written by our selves. As far as we are concerned, also these tests are scientific, correct and relevant.

4.5.5.1 Contamination test 1
In this test, samples from wheel arch liners, described in chapter 4.4, 100 by 150 mm were punched out and weighed. After this the edges were sealed to prevent absorption of water and mud, which the samples were about to be submerged in, trough the edges. We wanted the water and mud to intrude the samples through the surfaces usually exposed on a wheel arch liner assembled in a car. The samples were now weighed again before placed horizontally in the dirt. After ten minutes, including a turn over, the samples were picked up and hanged vertically to drain. After another ten minutes the samples were

weighed again and then when dried for 72 hours, weighed a last time. The composition of the dirt used, is however taken out of a test included in the corporate standard, Mud test, method id. 42201. The dirt is here used for an accelerating corrosion test for the assessment of the corrosion resistance of light metal wheels. Since a wheel arch liner is exposed for the very same kind of environment we considered the dirt as suitable and useful. The composition of the dirt is as follows:

Table 2 Composition of dirt

Substance	Per cent by weight
Sea sand, washed (grain size 0.1-0.3 mm)	88.8
Kaolin	8.8
Active carbon (powder)	1.4
Sodium Chloride (NaCl)	0.5
Calcium Cloride ($CaCl_2x2H_2O$)	0.5
Distilled water	aprox. 35 g per 100 g dry substance

We had to increase the amount of water however, to be able to pursue the test as wished. A suitable amount of water in our test turned out to be 70 g per 100 g dry substance. The results of the test is presented in Table 12 and Figure 52 in chapter 5.5.1.

4.5.5.2 Contamination test 2

For this test we chose to punch round samples from wheel arch liners with a diameter of 110 mm. Since the samples did not need to have sealed edges for this test, they were weighed and exposed for dirt directly. A certain amount of the same dirt as used in contamination test 1, were spread on the inside of each sample, in other words on the surface facing the wheel, since this side is the most exposed one. After ten minutes with the dirt on top of the samples, they were hanged horizontally with the dirt turned downwards for another ten minutes before weighing. When dried for 72 hours, the samples were weighed a third time before vibrated and weighed a last time. The results of the test is presented in Table 15 and Figure 53 in chapter 5.5.2.

4.5.5.3 Contamination test 3

In this test we wanted to simulate real-life conditions. The best way to simulate this is to apply our wheel arch liners, described in chapter 4.4, on an existing car and drive in real conditions. Since all wheel arch liners are of different geometry we came to the conclusion that the best way to do this test was to punch out two samples from each wheel arch liner and assemble them on a Volvo front wheel arch liners. The samples were 100 by 150 mm and their edges were sealed to prevent that water was absorbed this way. All samples were weighed before and after they were sealed. As fixture we used two left-hand and two right-hand Volvo V50 front wheel arch liners. In studies of used cars, we saw which area of the wheel arch liner that was most exposed for sprayed gravel, water and dirt. In this area we made the holes. Four holes, each 80 by 130 mm, were punched out at the rear of each wheel arch liner. The samples were assembled over the holes from the inside of the wheel arch liners with rivets. To make the test as fair as possible we placed the two samples of each material in different cars and in different locations. Then the wheel arch liners were assembled on two Volvo V50 cars, see Figure 37.

Figure 37 Emplacement of samples in contamination test 3

The test proceeded for three weeks and the cars drove 2600 km each. Then the samples were disassembled and weighed. First we weighed sample I and II of each model directly after they were disassembled. The samples were then dried for 72 hours and weighed again. The results from the tests are presented in Table 16, Table 17, Table 18 and Figure 54 in chapter 5.5.3.

4.5.6 Noise tests

Two of the most important tests are the noise tests. There is no Volvo Cars corporate standard or technical regulation that says how much a material should absorb. Since there is no recommendation, we need to set one for our own.

We consulted Bo Karlsson at the Noise and Vibration Center, for ideas' concerning noise. We showed him our material samples to hear what he had to say about them. In the following text we will describe different types of noise, the best way to minimize them and the best way to make tests of the material samples, with the help of Bo Karlsson and the literature we have read.

- Noise isolation is proportional to surface weight. This means that to make a wheel arch liner that is a good noise isolator the material should be of steel. But we do not want to do a wheel arch liner that is an insulator since the noise would just find another way in to the driving compartment and the driving-by noise will increase. What we want to achieve with this master thesis is to decrease the noise level and not use the wheel arch liner as an insulator.
- Noise absorption is the most important of the three noise properties. When Volvo Cars carries out tests of noise absorption of materials they use an Alpha Cabin. This is a noise isolated room with advanced measure equipments. In an Alpha Cabin you need a sheet of the material 1m by 1.2 m. We did not have access to sheets of that size so we needed to come up with another idea. We consulted Mikael Norgren at the Noise and Vibration Center He suggested that we used the Kundt tube but Volvo Cars does not have a Kundt tube. Mikael Norgren had however a contact at Chalmers University of Technology , Börje Wijk. Chalmers had one and it was possible to go there and perform our tests. It worked on the

range 20-2000 Hz. Bo Karlsson said that the interesting range is over 600 Hz and the most interesting range is 1000-2000 Hz.

- Splash noise is generated when water and gravel is traveling at high speed and hits a hard surface. The best way to minimize splash noise is to use lightweight soft materials that will break water droplets with maximum gentleness. Volvo Cars had no equipment to make this kind of test so we had to come up with a test of our own. A test that measures the splash noise in a simple but still reliable way.

4.5.6.1 Noise absorption test

The test is performed in a Kundts tube, see Figure 38. The Kundts tube works in the following way: There is a speaker in the wooden box that transmits a "white noise" in the range 20-2000 Hz. The samples are placed at the top of the steel tube. A microphone registers the noise after the absorption and compares it with the unchanged noise. This gives a diagram of the absorption at different frequencies. The samples were punched out and had a diameter of 100 mm. The result from this test is presented in Figure 55 in chapter 5.6.1.

Figure 38 Kundts tube

4.5.6.2 Splash noise test

As mentioned before Volvo has no equipment for this kind of test. When Volvo Cars makes noise measurements they take a whole wheel arch liner and assemble it on car and drive over different types of surfaces. We did not have time and material to do this type of test. What we wanted to do was to do a simple test so we could make evaluations of the materials. We came up with the following idea, see Figure 39:

- We used the same sample as in noise absorption test
- The material samples are fixated in a fixture
- A sphere is released from 0.5 m, the sphere has a radius of 6 mm and a weight of 6.9 g
- A noise level meter registers the noise level

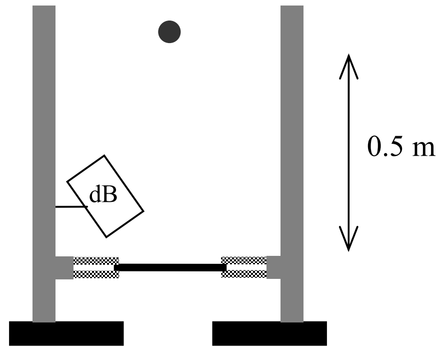


Figure 39 Splash noise test equipment

The noise level meter measures the dB (lin) which means unweighted decibels. Unweighted means a noise pressure level (in dB (lin)) measured using an instrument with a flat or linear frequency response. dB (lin) shall not be mix up with dB (A), which means A-weighted decibels. A-weighted means a standardized frequency response (in dB (A)) used in noise measuring instruments and corresponding approximately to the response of a human ear. When the noise level meter measures the dB (lin) it measures the peak and this for a very short time. We have impulse noise and that is why we used this type of noise pressure level. The result from the test is presented in Table 22 and Figure 56 in chapter 5.6.2.

4.5.7 Cost

When it comes to production of technical parts in large scales, the costs always have a big influence on the solution. Small differences in the technical solutions or in the production process may have a tremendous affect on the costs. In our case, it has been mostly difficult to get a clear picture of the costs depending mainly on the choice of material. A supplier very seldom opens up and provides a customer with price examples unless serious offers are requested. In our case, we have however been able to get a rather fair picture of the costs for a complete wheel arch liner in different materials including its manufacturing costs. This after discussions with both suppliers and internal departments at Volvo Cars. We do not have any exact numbers but we have approximate differences in costs depending on choice of material and based on earlier purchases we get a rough cost calculation. See Table 24 and Figure 57 in chapter 5.7

4.6 Geometry solutions

When designing the geometry of a wheel arch liner, there are several functions and restrictions to take into consideration. The solutions sometimes seem unnecessary complicated but all lines, surfaces or cuts are there for a reason.

4.6.1 Stiffness

Integrating ribs at the top of the wheel arch liner, see Figure 40 will increase the stiffness and if the ribs are designed correct, it will point the water spray downwards. In this case less water will spray on the side of the wheel arch line facing the engine bay. A second way to increase the stiffness is to fold the edge perpendicular and/or make the edge round, see Figure 40.

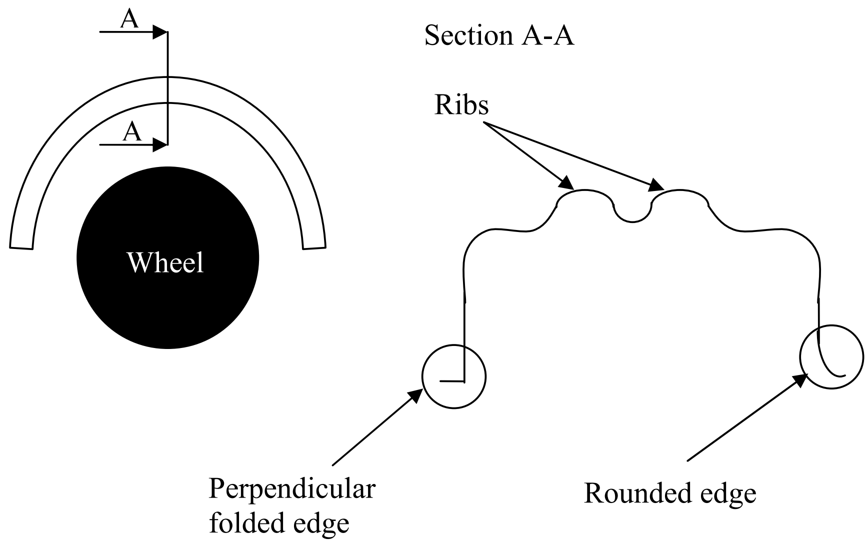


Figure 40 Wheel arch liner with ribs

4.6.2 Moving/rotating parts

To fulfill the regulations regarding distance to moving/rotating parts, we looked at competitors cars and found one solution that used a tube that was put over the driveshaft but it was a separate part. We looked for some alternative ways to integrate something like a tube. An idea we had was to make a shelter/roof over the moving/rotating part. In this case we thought that since the spurt comes mainly from the contact area between the wheel and the road, the spurt should have an angel so our "roof" will capture it. It will work better than a wall all the way down from the wheel arch liner to the moving/rotating part since the spray can come under it and up, see Figure 41.

The "roof" have the shape of an arch, see section A-A in Figure 41. It gives more protection since the rotating parts are round. Another benefit of the arch shaped roof is that it gives more stiffness to the roof, in case of weight increase due to snow and/or ice buildup.

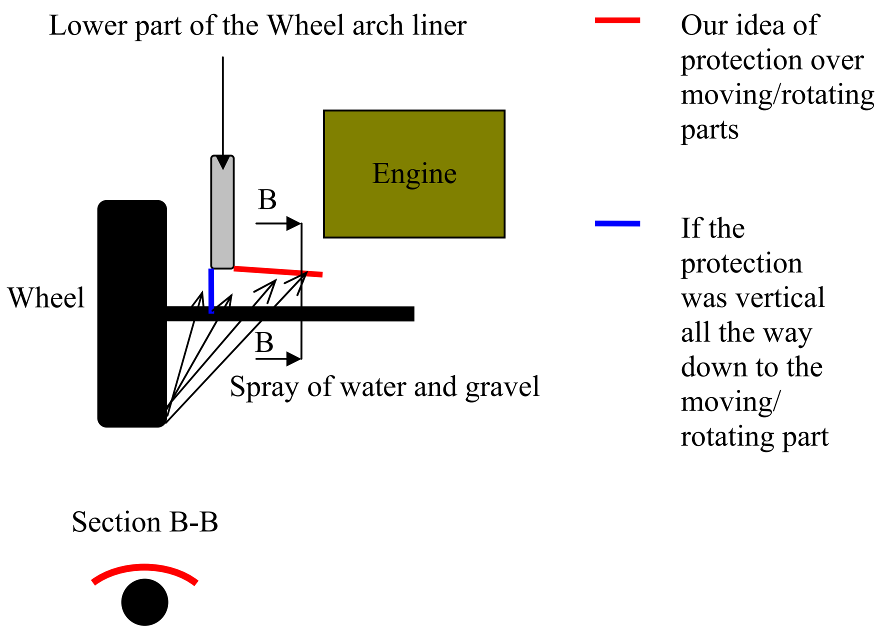


Figure 41 Wheel arch liner with our "roof"

Figure 42 Moving/rotating parts XC90

4.6.3 Gap

A way to seal the gap is to extend the wheel arch liner parallel to the under-shield, fold it over and fix the two parts together, see Figure 43. This is not that easy due to the fact that the sub frame (the under-shield is assembled on the sub frame) is moving in relation to the rest of the car. The wheel arch liner can not lie against the sub frame due to corrosion, but we still want to seal the gap as described above. To solve this came up with this idea: the idea is to use a geometry that is adjusted and that works so that the distance between the sub frame and the wheel arch liner do not fall short of the given limitation. The idea is presented in Figure 44. We have not been able to test the idea on a real wheel arch liner except in theory.

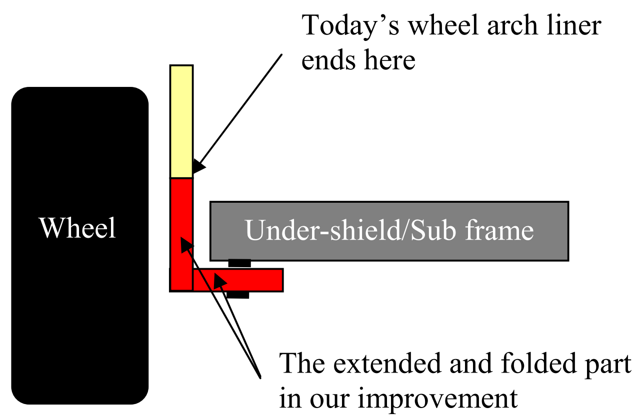


Figure 43 Wheel arch liner with the extended and folded part

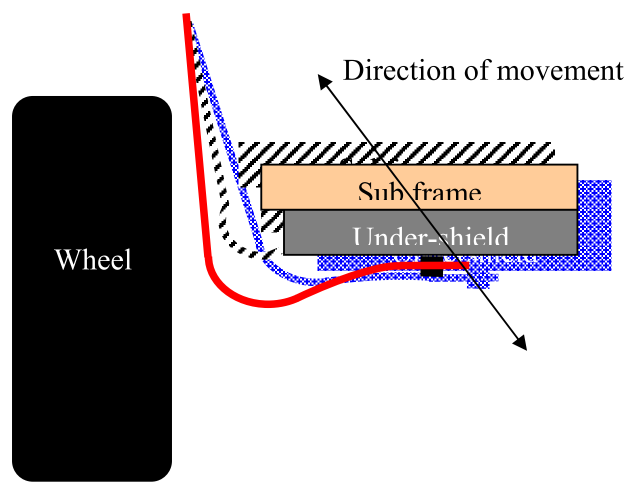


Figure 44 Wheel arch liner with the special geometry for solving the problem with moving sub frame

4.6.4 Corrosion

One way to reduce the risks of the sandpaper effect is to make sure that the wheel arch liner does not rub against the metal. If it must, make sure that it has enough assembling points to prevent it from moving in all directions. Another way of solving this problem is to put a thin foil maid from for example PP. The foil can be placed locally on the wheel arch liner in areas that are in contact with sensitive surfaces.

4.6.5 Folding line and Splash shield

We found out that one way to make a wheel arch liner that is easy to assemble and that still will cover much of the important areas is to make a folding line. The folding line will make it possible to fold a part of the wheel arch liner, see Figure 45. This has the advantage that the assembler would not have to assemble the part of the wheel arch liner in the tight area at the same time as the rest of the wheel arch liner is being assembled. With materials like those described in chapter 4.4 it will have the advantage of being easy to fold.

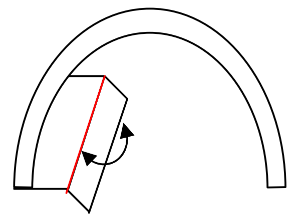


Figure 45 Wheel arch liner with folding line

If the splash shield is integrated in the wheel arch liner, then it is one part less to assemble. Another advantage is that it might be easier to assemble the wheel arch liner with integrated splash shield than to assemble first the wheel arch liner and after this the splash shield.

5 Result

All the tests we have performed have generated a great amount of values and results. Most of them are compiled in both tables and diagrams to facilitate an analyze. Also the decided limits for a certain grade are presented for each test and received grade for the material samples. All tests have a grading scale from 1 to 10. An exception is the result of the developed geometry which is presented with pictures from the Catia-model. These results are not graded or evaluated as we have described earlier.

5.1 Determination of thickness and density

The thickness vary over the wheel arch liners, especially around the edges and in sharp corners but the material samples are taken from equivalent and smooth areas. The evaluation is based on the density.

Table 3 Material density and weight per area unit

Manufacture	Model	Density [g/cm3]	Weight [g/m2]
Alfa Romeo	166	0.31	922
Audi	A6 TDI	0.29	1324
Audi	A8	0.44	1629
Maybach	Maybach	0.39	1229
Mercedes Benz	A-Class	0.26	827
Mercedes Benz	S-class	0.26	1084
Volvo	S40/V50	0.93	1904
Volvo	XC90	0.28	1009
Volkswagen	Touareg V5 TDI	0.37	1558

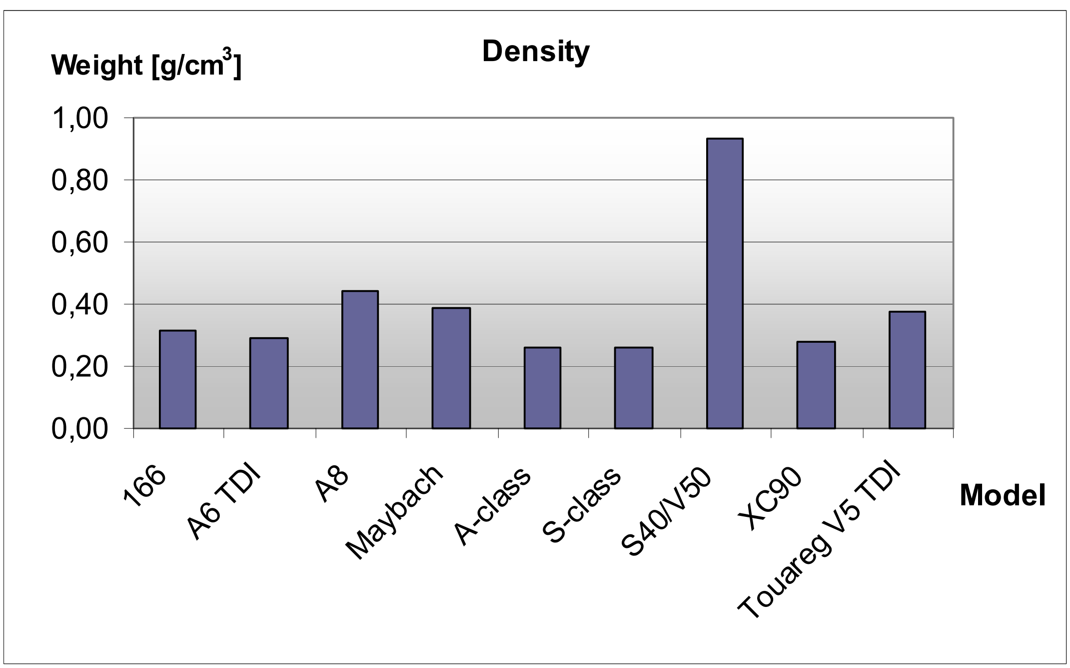


Figure 46 Material density

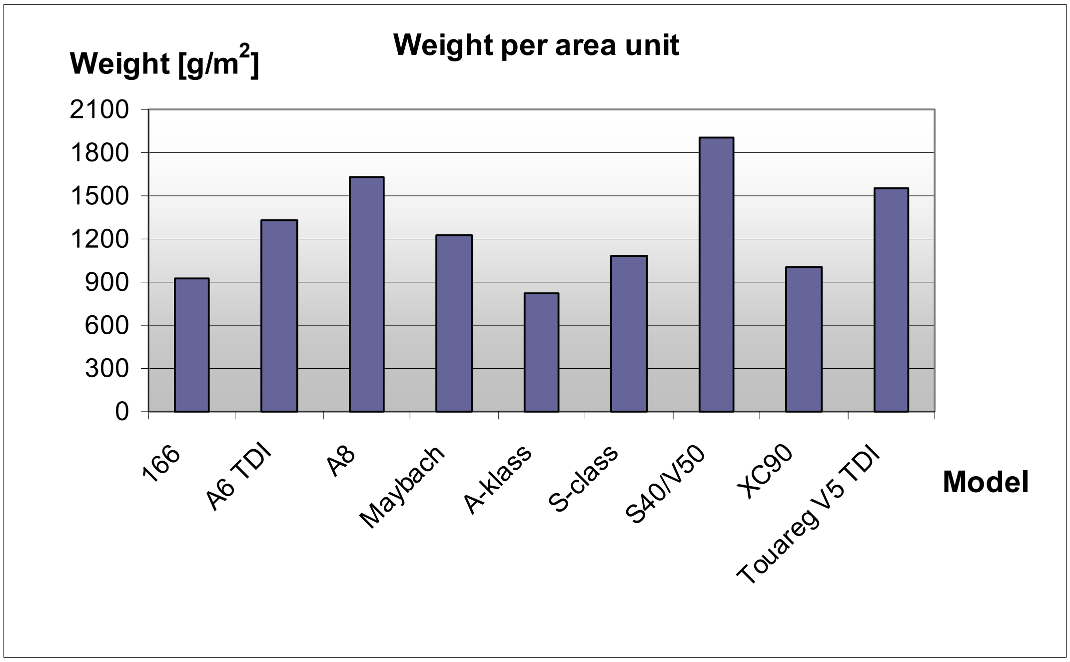


Figure 47 Weight per area unit

Table 4 Grade limits and reached grades for material samples

Result [g/cm3]	Grade	Model	Grade
X>0,90	1	166	7
0,70<X<0,90	2	A6 TDI	8
0,50<X<0,70	3	A8	5
0,45<X<0,50	4	Maybach	6
0,40<X<0,45	5	A-class	8
0,35<X<0,40	6	S-class	8
0,30<X<0,35	7	S40/V50	1
0,25<X<0,30	8	XC90	8
0,20<X<0,25	9	Touareg V5 TDI	6
X<0,20	10		

5.2 Wear resistance

The results are measured after strong wearing from sandpaper, grain size P40. For further description, see chapter 4.5.2. The evaluation is based on visual assessment due to the differences in the materials.

Table 5 Wear resistance

Manufacture	Model	T_0 [mm]	T_1 [mm]
Alfa Romeo	166	2.93	1.75
Audi	A6 TDI	4.53	3.48
Audi	A8	3.67	3.21
Maybach	Maybach	3.17	2.62
Mercedes Benz	A-class	3.14	2.25
Mercedes Benz	S-class	4.19	3.64
Volvo	S40/V50	2.04	unchanged
Volvo	XC90	3.59	2.59
Volkswagen	Touareg V5 TDI	4.26	unchanged

T_0 – thickness before test, T_1 – thickness after test

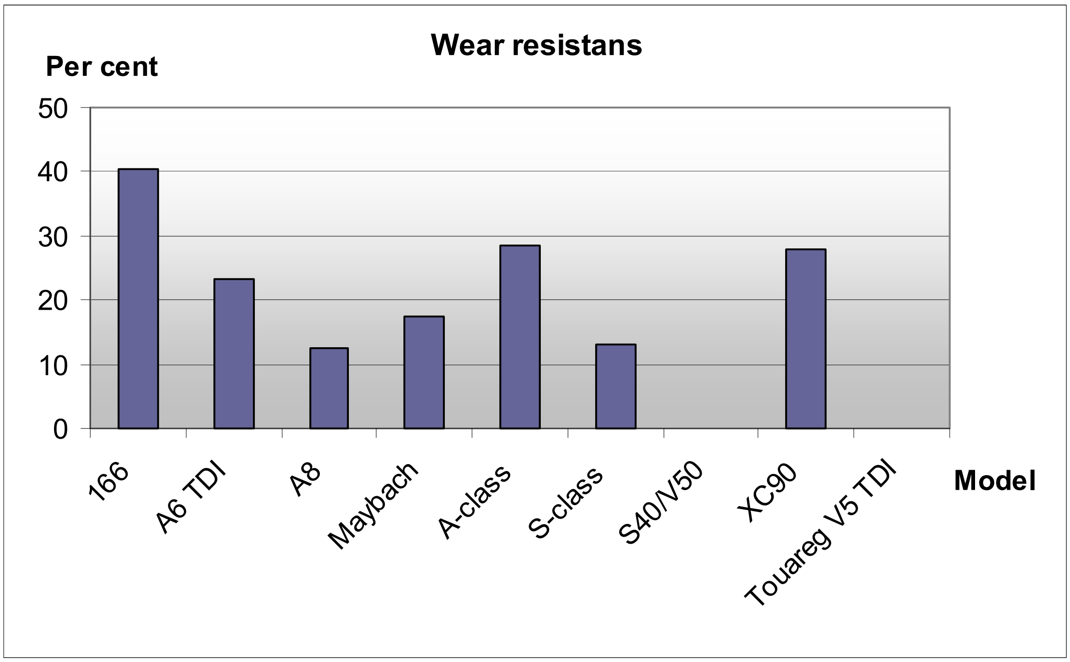


Figure 48 Wear resistance, wear in per cent

Table 6 Grade limits and reached grades for material samples

Result	Grade	Model	Grade
	1	166	5
	2	A6 TDI	5
	3	A8	9
	4	Maybach	7
Visual assessment	5	A-class	3
	6	S-class	5
	7	S40/V50	10
	8	XC90	5
	9	Touareg V5 TDI	10
	10		

5.3 Stiffness test

Some materials gave quite varying results but the average top force shows a fair picture of the materials. We have also chosen to present the average top force together with the density. The evaluation is however based on the average top force for each material. Raw data from the test is presented in Appendix 2.

Table 7 Stiffness test

Manufacture	Model	Density [g/cm^3]	Average top force [N]
Alfa Romeo	166	0.31	7.19
Audi	A6 TDI	0.29	13.49
Audi	A8	0.44	17.54
Maybach	Maybach	0.39	7.53
Mercedes Benz	A-class	0.26	4.22
Mercedes Benz	S-class	0.26	3.91
Volvo	S40/V50	0.93	55.66
Volvo	XC90	0.28	9.77
Volkswagen	Touareg V5 TDI	0.37	11.91

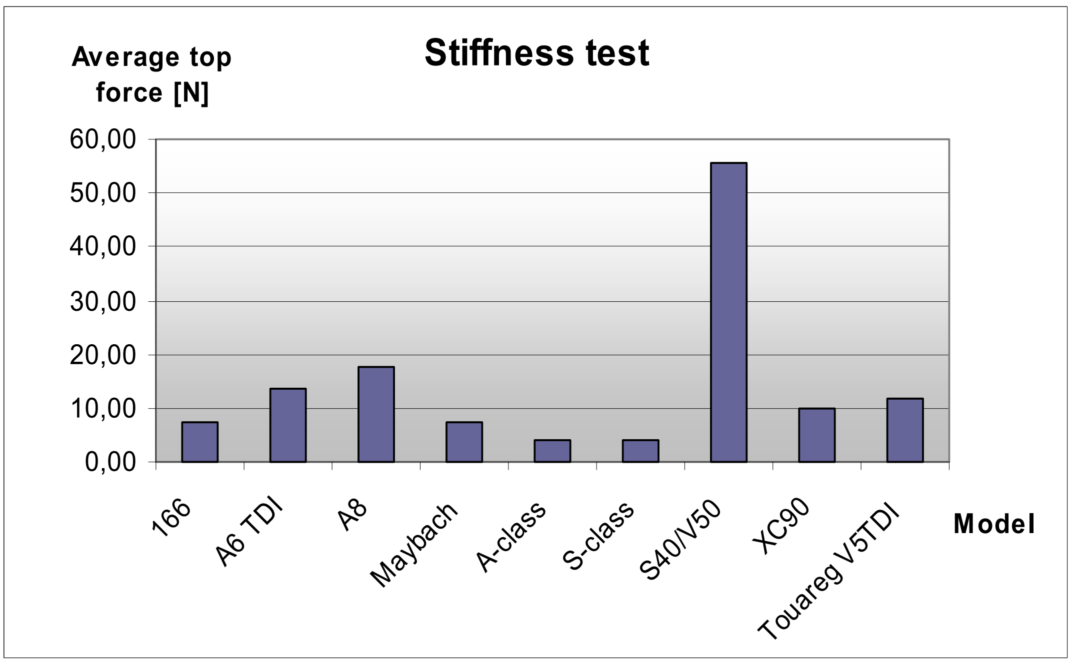


Figure 49 Average top value from stiffness test

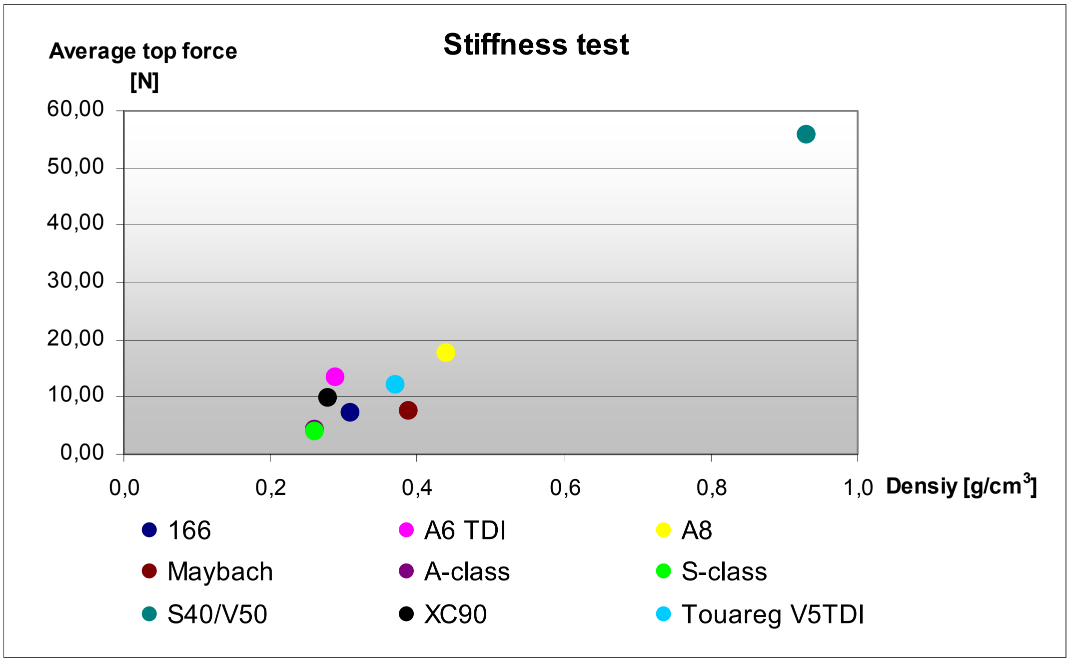


Figure 50 Stiffness test

Table 8 Grade limits and reached grades for material samples

Result [N]	Grade	Model	Grade
X<5	1	166	2
5<X<10	2	A6 TDI	3
10<X<15	3	A8	4
15<X<20	4	Maybach	2
20<X<25	5	A-class	1
25<X<30	6	S-class	1
30<X<35	7	S40/V50	10
35<X<40	8	XC90	2
40<X<45	9	Touareg V5 TDI	3
X>45	10		

5.4 Charpy test

The main purpose with the Charpy test is to ensure that the materials do not lose shape or even break but it is also a complement to the stiffness test. The capacity to absorb energy reflects the stiffness rather well. The evaluation is however based on a visual assessment.

Table 9 Dry Charpy test

Manufacture	Model	Average energy absorption [J]	Comment
Alfa Romeo	166	0.026	Requirement fulfilled
Audi	A6 TDI	0.147	Requirement fulfilled
Audi	A8	0.090	Requirement fulfilled
Maybach	Maybach	0.035	Requirement fulfilled
Mercedes Benz	A-class	0.081	Requirement fulfilled
Mercedes Benz	S-class	0.114	Requirement fulfilled
Volvo	S40/V50	0.374	Requirement fulfilled
Volvo	XC90	0.048	Requirement fulfilled
Volkswagen	Touareg V5 TDI	0.121	Requirement fulfilled

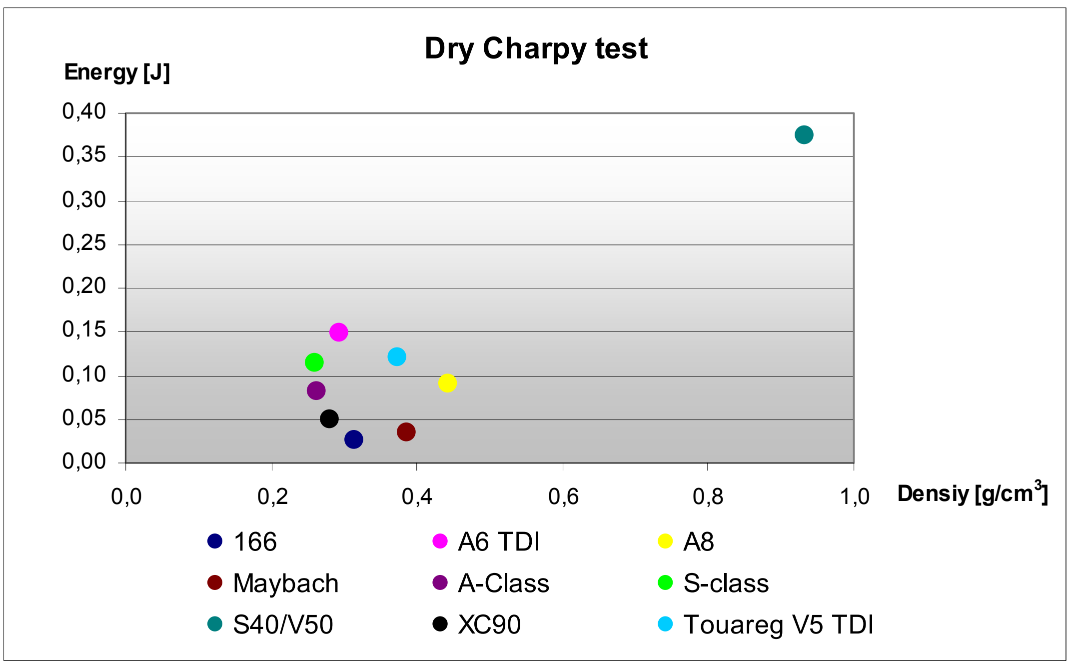


Figure 51 Dry Charpy test

Table 10 "Wet" Charpy test

Manufacture	Model	Average energy absorption [J]	Comment
Alfa Romeo	166	0.097	Requirement fulfilled
Audi	A6 TDI	0.295	Requirement fulfilled
Audi	A8	0.464	Requirement fulfilled
Maybach	Maybach	0.317	Requirement fulfilled
Mercedes Benz	A-class	0.282	Requirement fulfilled
Mercedes Benz	S-class	0.577	Tendency of separation between layers
Volvo	S40/V50	0.385	Requirement fulfilled
Volvo	XC90	0.189	Requirement fulfilled
Volkswagen	Touareg V5 TDI	0.783	Broken polymer layer

The average energy absorption is of no use, the results only shows that the ice in the material makes the materials stiffer. The test was performed only to see if the materials could stand the impact.

Table 11 Grade limits and reached grades for material samples

Result	Grade	Model	Grade
Visual assessment	1	166	10
	2	A6 TDI	10
	3	A8	10
	4	Maybach	10
	5	A-class	10
	6	S-class	7
	7	S40/V50	10
	8	XC90	10
	9	Touareg V5 TDI	5
	10		

S-class and Touareg V5 TDI reaches lower grades due to the problems in “Wet” Charpy test.

5.5 Contamination tests

Because of the great importance of the contamination properties, we have carried out not less than three different contamination tests.

5.5.1 Contamination test 1

The test was carried out with standardized dirt but the test itself is written by us. The evaluation is based on results from both the wet and the dried test samples.

Table 12 Sample weights from contamination test 1

Manufacture	Model	Weight [g]	W_1 [g]	W_2 [g]	W_3 [g]
Alfa Romeo	166	14.20	15.00	33.10	19.70
Audi	A6 TDI	17.90	19.00	40.40	24.20
Audi	A8	24.60	25.50	55.60	31.10
Maybach	-	19.10	20.00	52.30	26.20
Mercedes	A-Class	12.40	13.00	34.10	16.70
Mercedes	S-class	17.10	18.80	29.30	21.20
Volvo	S40/V50	31.40	31.40	32.10	31.40
Volvo	XC90	16.40	17.00	23.40	19.20
Volkswagen	Touareg V5 TDI	21.20	22.00	32.80	23.50

W_1 – weight with sealed edges, W_2 – weight wet sample, W_3 – weight dried sample

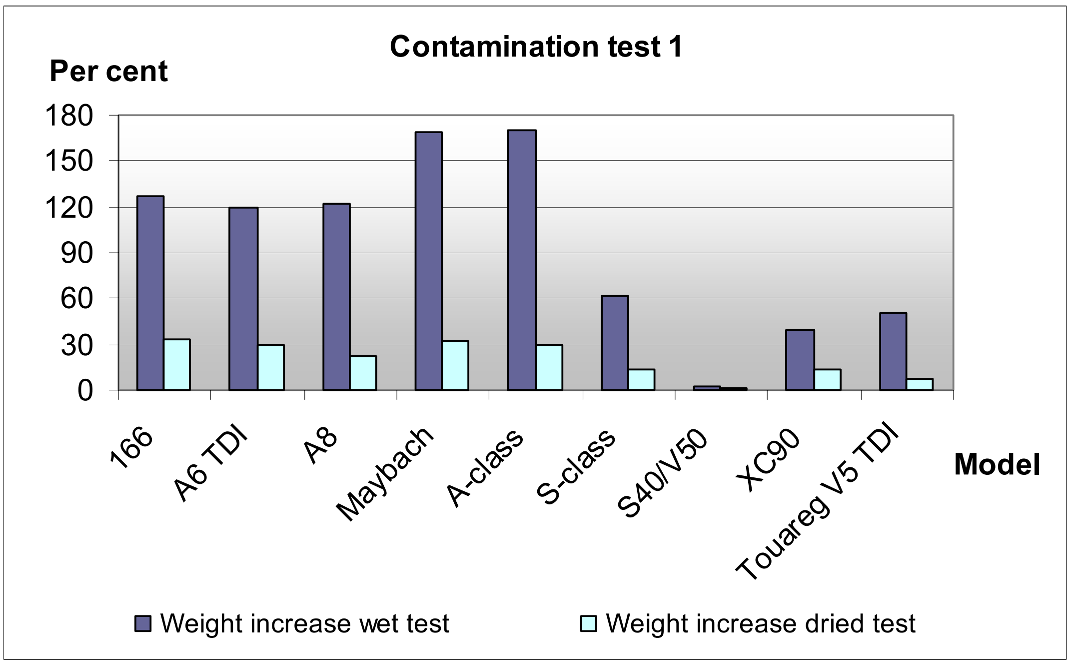


Figure 52 Weight increase contamination test 1

Table 13 Grade limits and reached grades for material samples in Contamination test 1, wet.

Result [%]	Grade	Model	Grade
X>150	1	166	4
140<X<150	2	A6 TDI	5
130<X<140	3	A8	4
120<X<130	4	Maybach	1
110<X<120	5	A-class	1
90<X<110	6	S-class	8
70<X<90	7	S40/V50	10
50<X<70	8	XC90	9
30<X<50	9	Touareg V5 TDI	8
X<30	10		

Table 14 Grade limits and reached grades for material samples in Contamination test 1, dried.

Result [%]	Grade	Model	Grade
X>40	1	166	3
34<X<40	2	A6 TDI	3
29<X<34	3	A8	6
26<X<29	4	Maybach	3
23<X<26	5	A-class	3
20<X<23	6	S-class	8
15<X<20	7	S40/V50	10
10<X<15	8	XC90	8
5<X<10	9	Touareg V5 TDI	9
X<5	10		

5.5.2 Contamination test 2

The test was carried out with standardized dirt but the test itself is written by us. We are however rather uncertain if the test correlates with the reality and we have therefore decided to exclude it from the evaluation.

Table 15 Sample weights from contamination test 2

Manufacture	Model	Weight [g]	W_1 [g]	W_2 [g]	W_3 [g]
Alfa Romeo	166	9.10	30.30	22.60	16.10
Audi	A6 TDI	11.40	22.70	17.90	13.10
Audi	A8	15.10	37.70	28.40	19.80
Maybach	Maybach	10.40	27.30	20.70	18.60
Mercedes	A-Class	10.70	34.70	26.50	11.90
Mercedes	S-class	10.20	15.30	13.30	12.30
Volvo	S40/V50	18.70	22.60	21.20	20.60
Volvo	XC90	10.10	17.40	14.90	10.60
Volkswagen	Touareg V5 TDI	16.90	20.90	19.50	18.40

W_1 – weight wet sample, W_2 – weight dried sample, W_3 – weight dried and vibrated sample

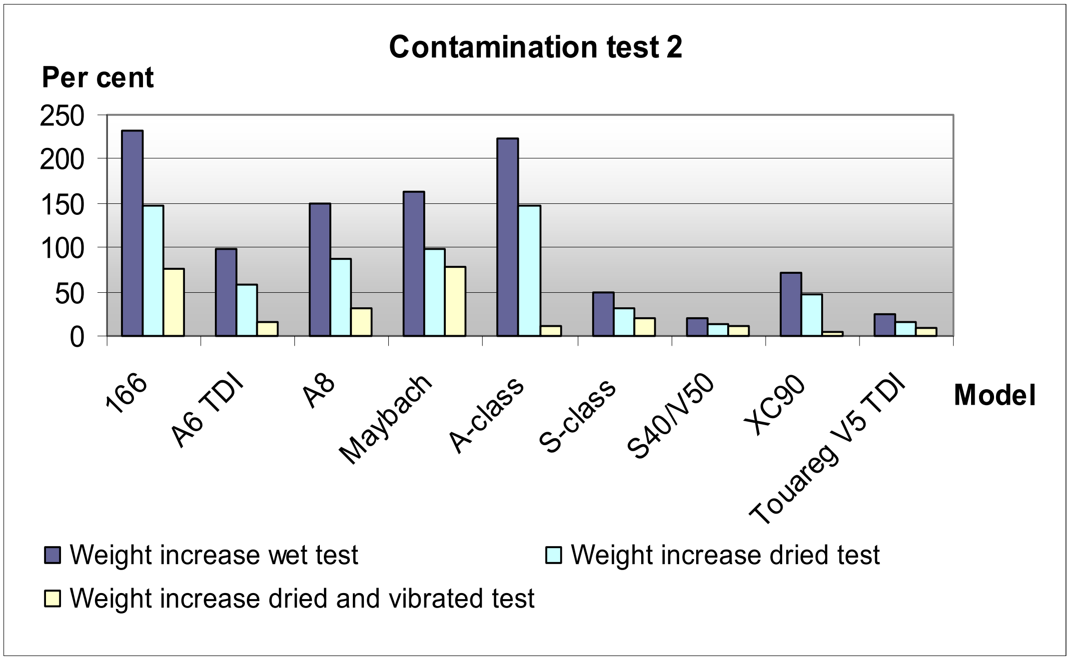


Figure 53 Weight increase contamination test 2

5.5.3 Contamination test 3

Unlike contamination test two, this test is a hundred percent alike the reality. It was carried out over a long period of time and over a long distance and is without a doubt the most important contamination test that we performed. The evaluation is based on the average weight increase from both the wet and the dried tests.

Table 16 Result from contamination test 3, **sample 1**

Manufacture	Model	Weight [g]	W_1 [g]	W_2 [g]	W_3 [g]
Alfa Romeo	166	13.4	13.8	30.0	18.3
Audi	A6 TDI	21.3	22.2	34.1	24.4
Audi	A8	24.7	25.4	51.8	31.0
Maybach	Maybach	17.6	18.3	41.7	23.6
Mercedes	A-class	12.9	13.4	44.0	21.1
Mercedes	S-class	15.3	16.2	25.2	17.3
Volvo	S40/V50	27.7	27.7	28.2	27.9
Volvo	XC90	14.9	15.6	41.9	21.0
Volkswagen	Touareg V5 TDI	24.5	25.2	49.2	27.1

W_1 – weight with sealed edges, W_2 – weight wet sample, W_3 - weight dried sample

Table 17 Result from contamination test 3, **sample 2**

Manufacture	Model	Weight [g]	W_1 [g]	W_2 [g]	W_3 [g]
Alfa Romeo	166	13.9	14.4	36.0	22.9
Audi	A6 TDI	20.4	21.2	37.6	24.9
Audi	A8	24.0	24.6	50.9	31.6
Maybach	Maybach	18.6	19.1	43.6	26.3
Mercedes	A-class	11.9	12.4	35.2	17.8
Mercedes	S-class	16.4	17.5	30.3	21.1
Volvo	S40/V50	26.6	26.6	27.1	26.8
Volvo	XC90	14.1	14.5	31.7	19.0
Volkswagen	Touareg V5 TDI	24.4	25.2	35.3	26.7

W_1 – weight with sealed edges, W_2 – weight wet sample, W_3 - weight dried sample

Table 18 Average weight increase from contamination test 3

Manufacture	Model	W_1 [%]	W_2 [%]
Alfa Romeo	166	138,15	47,37
Audi	A6 TDI	68,13	14,23
Audi	A8	108,23	25,92
Maybach	Maybach	132,34	34,41
Mercedes	A-class	214,40	52,53
Mercedes	S-class	68,44	14,57
Volvo	S40/V50	1,84	0,74
Volvo	XC90	149,25	34,08
Volkswagen	Touareg V5 TDI	69,68	6,95

W_1 – average weight increase wet test, W_2 – average weight increase dried test

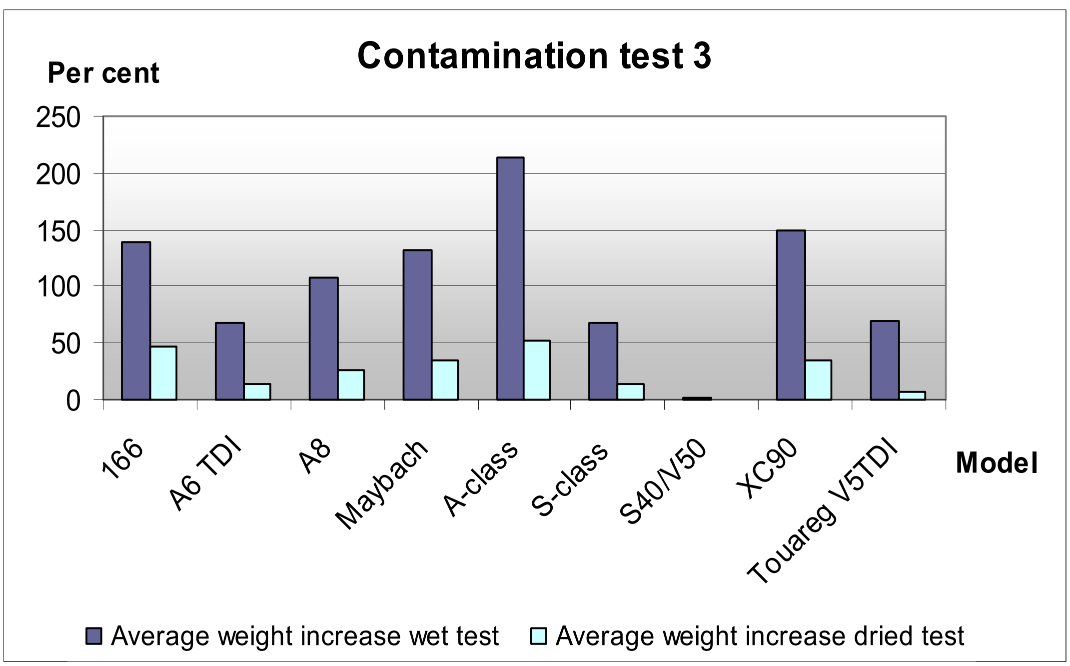


Figure 54 Average weight increase from contamination test 3

Table 19 Grade limits and reached grades for material samples in Contamination test 3, wet

Result [%]	Grade	Model	Grade
X>150	1	166	3
140<X<150	2	A6 TDI	8
130<X<140	3	A8	6
120<X<130	4	Maybach	3
110<X<120	5	A-class	1
90<X<110	6	S-class	8
70<X<90	7	S40/V50	10
50<X<70	8	XC90	2
30<X<50	9	Touareg V5 TDI	8
X<30	10		

Table 20 Grade limits and reached grades for material samples in Contamination test 3, dried

Result [%]	Grade	Model	Grade
X>40	1	166	1
34<X<40	2	A6 TDI	8
29<X<34	3	A8	5
26<X<29	4	Maybach	2
23<X<26	5	A-class	1
20<X<23	6	S-class	8
15<X<20	7	S40/V50	10
10<X<15	8	XC90	2
5<X<10	9	Touareg V5 TDI	9
X<5	10		

5.6 Noise tests

As described earlier the sound properties are highly important and this results in very high demands on the exactness of the noise tests. We have carried out two noise tests, both written by our selves, but never the less very accurate.

5.6.1 Noise absorption test

This is the first test to show clear differences between the materials and it is of course interesting to notice at a test of such importance. The results are not presented in figures due to the enormous amount and the curves are presented as trend lines (polynomial) to give a clear picture. Diagrams with raw data are presented in Appendix 3. The evaluation is based on visual assessment of these curves.

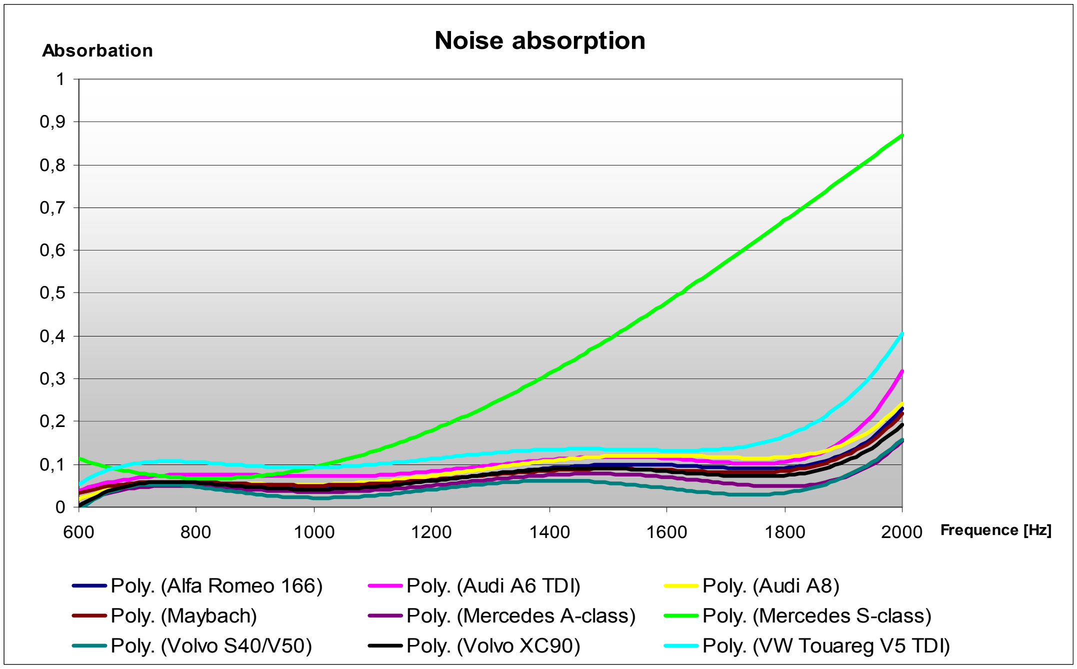


Figure 55 Noise absorption test

Table 21 Grade limits and reached grades for material samples

Result	Grade	Model	Grade
	1	166	3
	2	A6 TDI	4
	3	A8	4
	4	Maybach	3
Visual assessment	5	A-class	2
	6	S-class	10
	7	S40/V50	1
	8	XC90	3
	9	Touareg V5 TDI	6
	10		

5.6.2 Splash noise test

Also this test shows a clear result which in a way confirms the results from the noise absorption test. Notice that the scale on the Y-axis in Figure 56 begins at 100 dB (lin).

Table 22 Splash noise test

Manufacture	Model	Average splash noise [dB (lin)]
Alfa Romeo	166	110.65
Audi	A6 TDI	115.63
Audi	A8	116.63
Maybach	Maybach	112.33
Mercedes Benz	A-Class	115.98
Mercedes Benz	S-class	108.73
Volvo	S40/V50	130.68
Volvo	XC90	115.88
Volkswagen	Touareg V5 TDI	117.95

Average splash noise is the average value of all tests performed on the materials. Two samples and two tests on each.

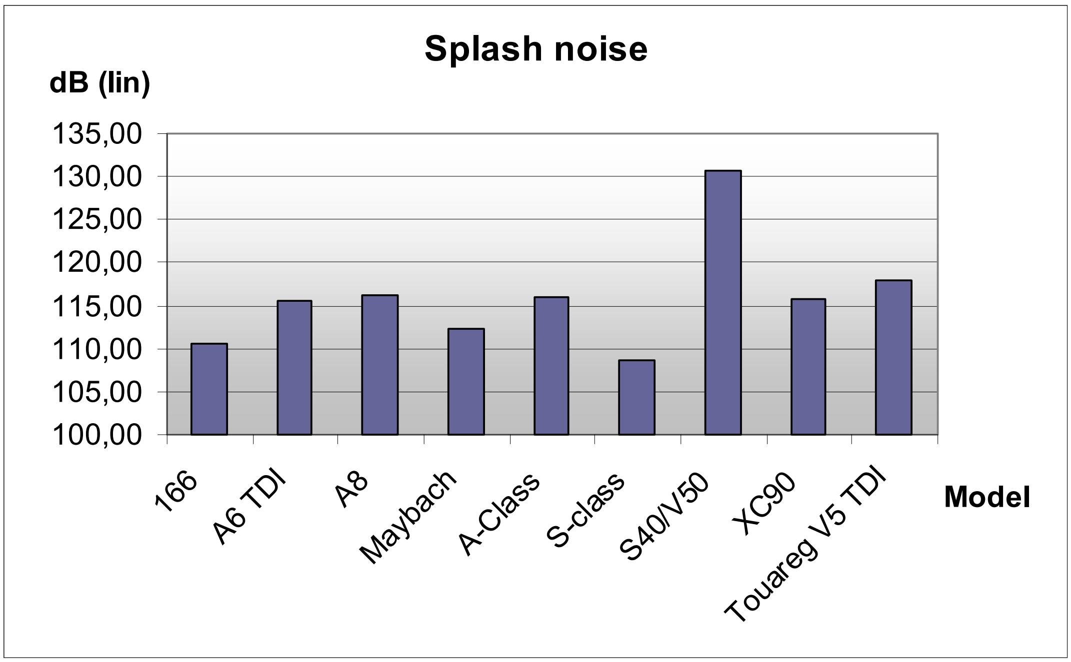


Figure 56 Splash noise test. Notice that the scale on the Y-axis begins at 100 dB (lin).

Table 23 Grade limits and reached grades for material samples

Result	Grade	Model	Grade
X>130,0	1	166	8
125,0<X<130,0	2	A6 TDI	6
122,5<X<125,0	3	A8	6
120,0<X<122,5	4	Maybach	8
117,5<X<120,0	5	A-class	6
115,0<X<117,5	6	S-class	9
112,5<X<115,0	7	S40/V50	1
110,0<X<112,5	8	XC90	6
107,5<X<110,0	9	Touareg V5 TDI	5
X<107,5	10		

5.7 Cost calculation

As mentioned before, these figures are rough calculations based on discussions with suppliers and Volvo Cars. The true costs will most definitely differ from the ones presented below after normal negotiations between Volvo Cars and different suppliers. The costs are not graded but instead we will later on present a result in form of cost per evaluation point for each material according to Volvo Cars' request.

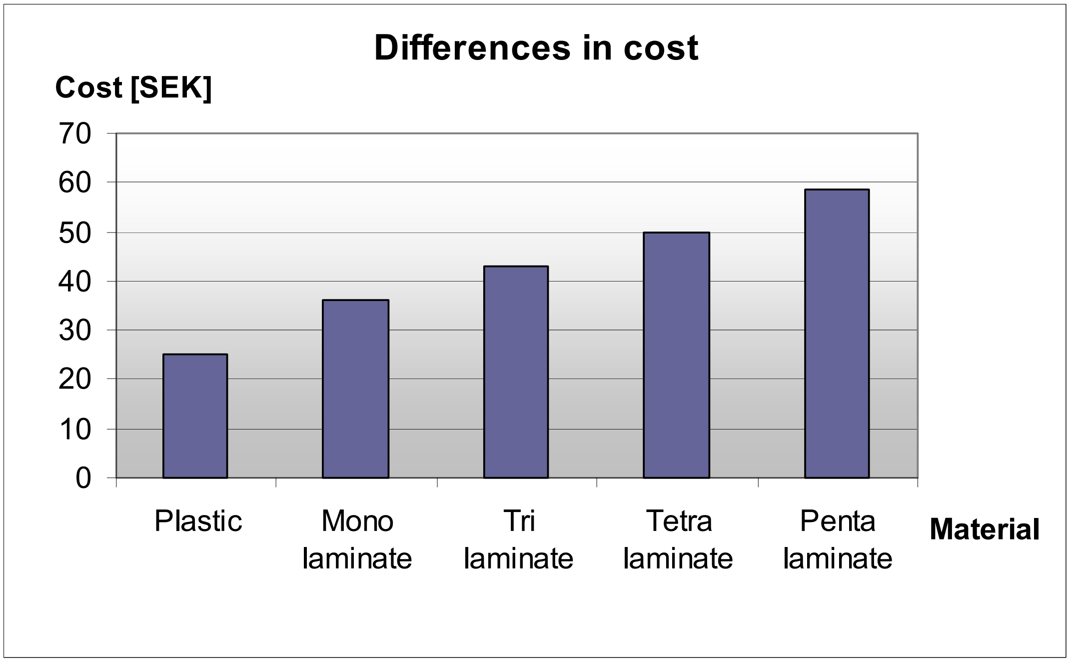


Figure 57 Differences in approximate cost per wheel arch liner depending on choice of material.

Table 24 Approximate cost per wheel arch liner

Manufacture	Model	Material	Cost [SEK]
Alfa Romeo	166	Tri laminate	52,50
Audi	A6 TDI	Tetra laminate	57,50
Audi	A8	Tri laminate	52,50
Maybach	Maybach	Tri laminate	52,50
Mercedes Benz	A-class	Mono laminate	35,00
Mercedes Benz	S-class	Penta laminate	62,50
Volvo	S40/V50	Plastic	25,00
Volvo	XC90	Mono laminate	35,00
Volkswagen	Touareg V5 TDI	Tri laminate	52,50

5.8 Evaluation

The chosen evaluation method for this work is the weighted objectives method which step by step is described in chapter 4.2.3. Presented here is the matrix were the criterions are compared in pairs to get a weighting. Chosen as criterions are the tests we have performed on the material samples.

Table 25 Weighting of criterions. 2 – more important than, 1- equally important as, 0 – less important than.

Criterion	A	B	C	D	E	F	G	H	I	J	∑	∑norm
A (Density)	-	2	2	2	2	2	2	2	0	0	14	**0,16**
B (Wear resistance)	0	-	1	0	1	0	1	0	0	0	3	**0,03**
C (Stiffness)	0	1	-	0	1	1	1	1	0	0	5	**0,06**
D (Charpy)	0	2	2	-	1	1	1	0	0	0	7	**0,08**
E (Contamination I, wet)	0	1	1	1	-	1	0	0	0	0	4	**0,04**
F (Contamination I, dried)	0	2	1	1	1	-	0	0	0	0	5	**0,06**
G (Contamination III, wet)	0	1	1	1	2	2	-	1	0	0	8	**0,09**
H (Contamination III, dried)	0	2	1	2	2	2	1	-	0	0	10	**0,11**
I (Noise absorption)	2	2	2	2	2	2	2	2	-	2	18	**0,20**
J (Splash noise)	2	2	2	2	2	2	2	2	0	-	16	**0,18**
										∑	90	**1,00**

The criterions are then used in the decision matrix and together with the test results it gives us a picture of how good the materials are in comparison to each other.

From a technical point of view, the material used for the wheel arch liner on Mercedes Benz S-class turns out to be by far the best. The material, a penta laminate, reaches a score of 8,01 out of maximum 10,00 and the second rating is not to be found higher than at 6,48. Unfortunately it is a rather expensive material which of course affects its result in a negative way when cost is taken into consideration. When looking at cost per evaluation point the solid plastic material is actually rather economical.

Table 26 Decision matrix

	Alternative																				
		Ideal		I66		A6 TDI		A8		Maybach		A-class		S-class		S40/V50		XC90		Touareg V5 TDI	
Criterion	λ	e	t	e	t	e	t	e	t	e	t	e	t	e	t	e	t	e	t	e	t
Density	0,16	10	1,56	7	1,09	8	1,24	5	0,78	6	0,93	8	1,24	8	1,24	1	0,16	8	1,24	6	0,93
Wear resistance	0,03	10	0,33	5	0,17	5	0,17	9	0,30	7	0,23	3	0,10	5	0,17	10	0,33	5	0,17	10	0,33
Stiffness	0,06	10	0,56	2	0,11	3	0,17	4	0,22	2	0,11	1	0,06	1	0,06	10	0,56	2	0,11	3	0,17
Charpy	0,08	10	0,78	10	0,78	10	0,78	10	0,78	10	0,78	10	0,78	7	0,54	10	0,78	10	0,78	5	0,39
Contamination I, wet	0,04	10	0,44	4	0,18	5	0,22	4	0,18	1	0,04	1	0,04	8	0,36	10	0,44	9	0,40	8	0,36
Contamination I, dried	0,06	10	0,56	3	0,17	3	0,17	6	0,33	3	0,17	3	0,17	8	0,44	10	0,56	8	0,44	9	0,50
Contamination III, wet	0,09	10	0,89	3	0,27	8	0,71	6	0,53	3	0,27	1	0,09	8	0,71	10	0,89	2	0,18	8	0,71
Contamination III, dried	0,11	10	1,11	1	0,11	8	0,89	5	0,56	2	0,22	1	0,11	8	0,89	10	1,11	2	0,22	9	1,00
Noise absorption	0,20	10	2,00	3	0,60	4	0,80	4	0,80	3	0,60	2	0,40	10	2,00	1	0,20	3	0,60	6	1,20
Splash noise	0,18	10	1,78	8	1,42	6	1,07	6	1,07	8	1,42	6	1,07	9	1,60	1	0,18	6	1,07	5	0,89
V(Aj)		**10,00**		**4,89**		**6,21**		**5,54**		**4,78**		**4,06**		**8,01**		**5,20**		**5,21**		**6,48**	
$V(A_j)_{norm} = V/V_{max}$		1,00		0,49		0,62		0,55		0,48		0,41		0,80		0,52		0,52		0,65	
Cost [SEK]		-		52,50		57,50		52,50		52,50		35,00		62,50		25,00		35,00		52,50	
Cost/point		**-**		**10,74**		**9,26**		**9,47**		**10,99**		**8,63**		**7,80**		**4,81**		**6,72**		**8,10**	

5.9 Developed geometry

In this chapter we will present our solutions concerning the geometry. The figures in this chapter are taken from our CAD-model. We made the CAD-model in a CAD-program named Catia V5.

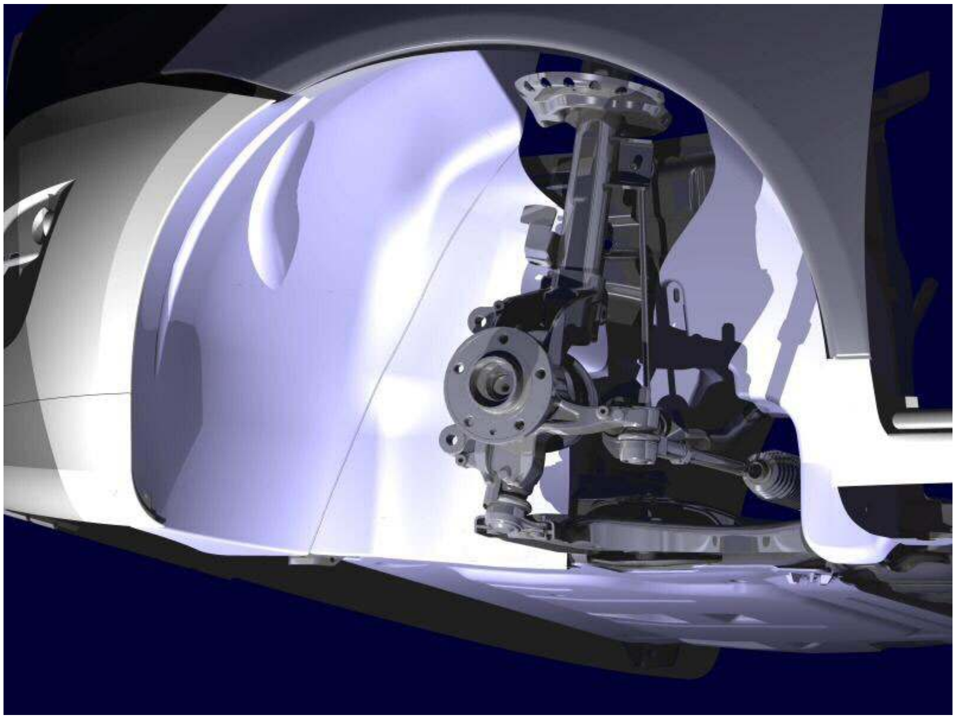


Figure 58 The wheel arch liner with the surrounding parts

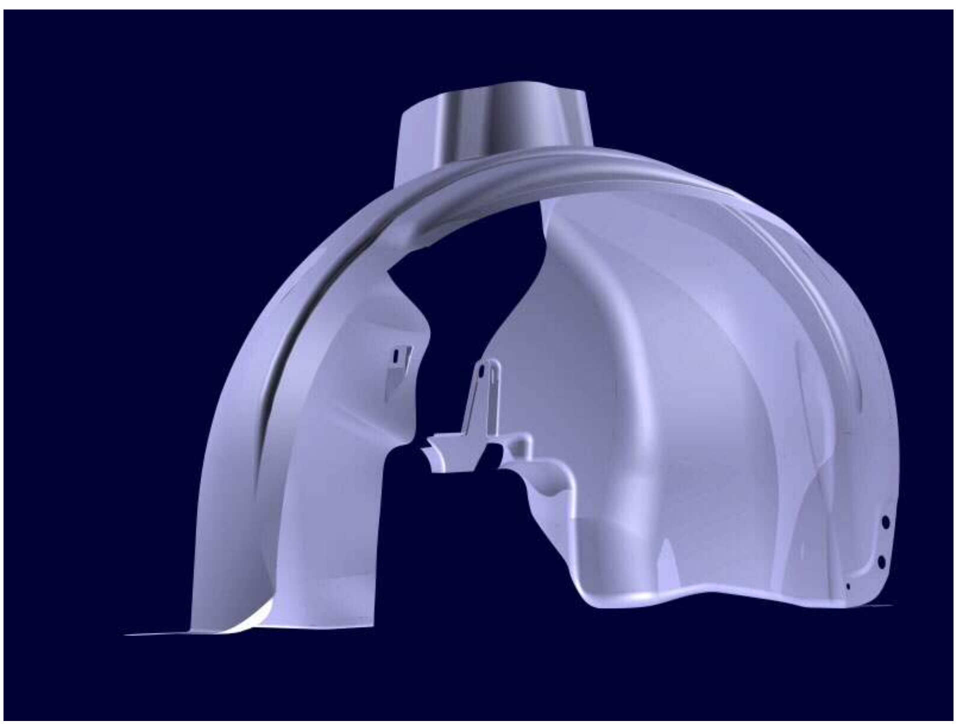


Figure 59 Our cad-model of the left front wheel arch liner

5.9.1 Stiffness

In our model we have chosen to use only one rib, this is only to show where we would recommend Volvo Cars to place the ribs. Perhaps it is enough with just one rib.

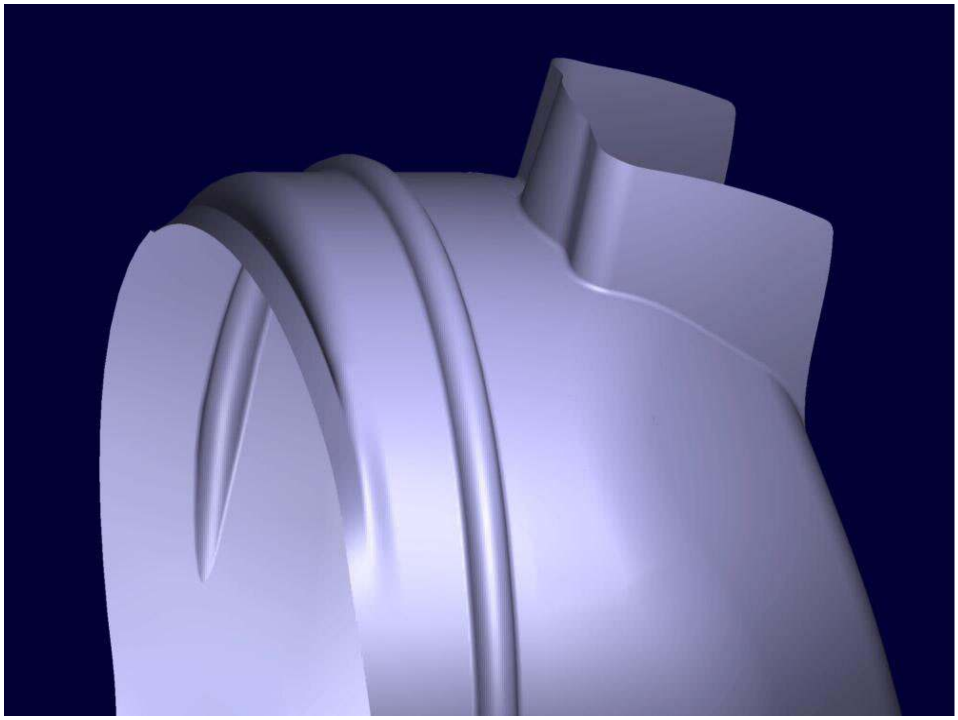


Figure 60 The integrated rib at the top of the wheel arch liner

To make the wheel arch liner even stiffer we have chosen to fold some edges which will make the part stiffer. It will also seal better.

Figure 61 Folded edge, picture taken at the bottom, at the front part of the wheel arch liner

5.9.2 Moving/rotating parts

The best way to cover and protect the moving/rotating parts is to use a shelter/roof described in chapter 4.6.2. We came up with a solution that fulfills the demands and that will protect the engine bay from water and dirt spray.

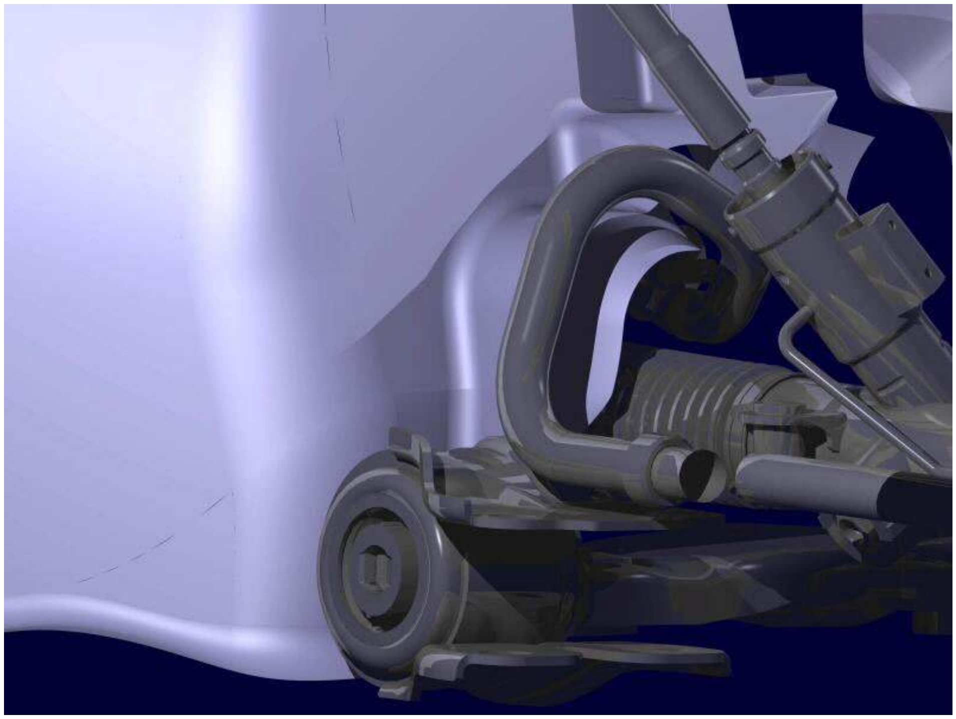


Figure 62 Picture of the "roof" taken from the engine bay

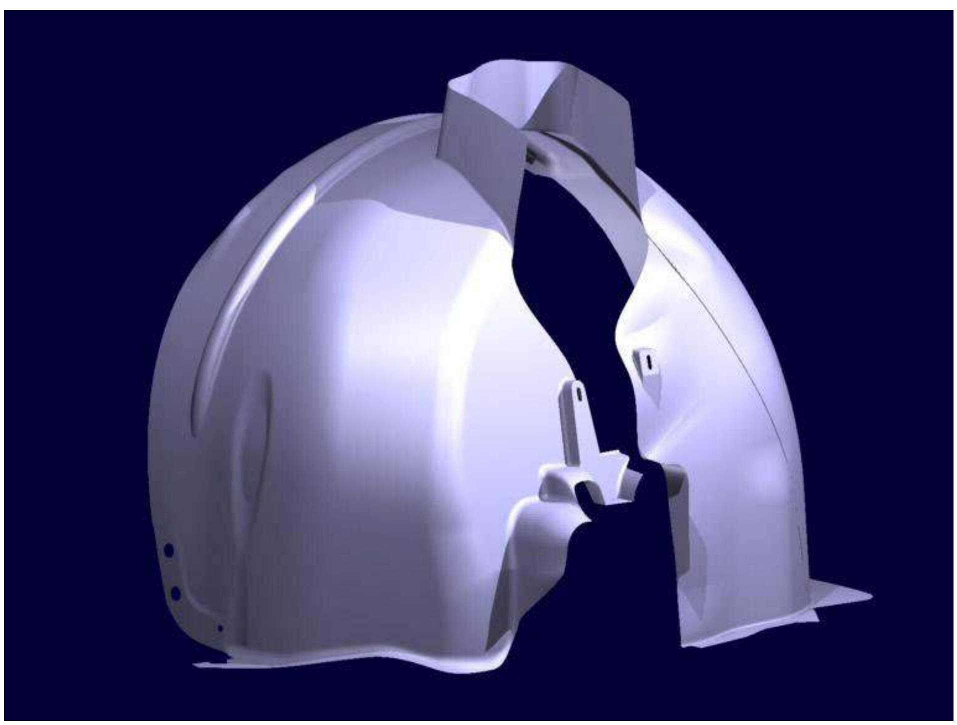


Figure 63 Picture taken from the engine bay

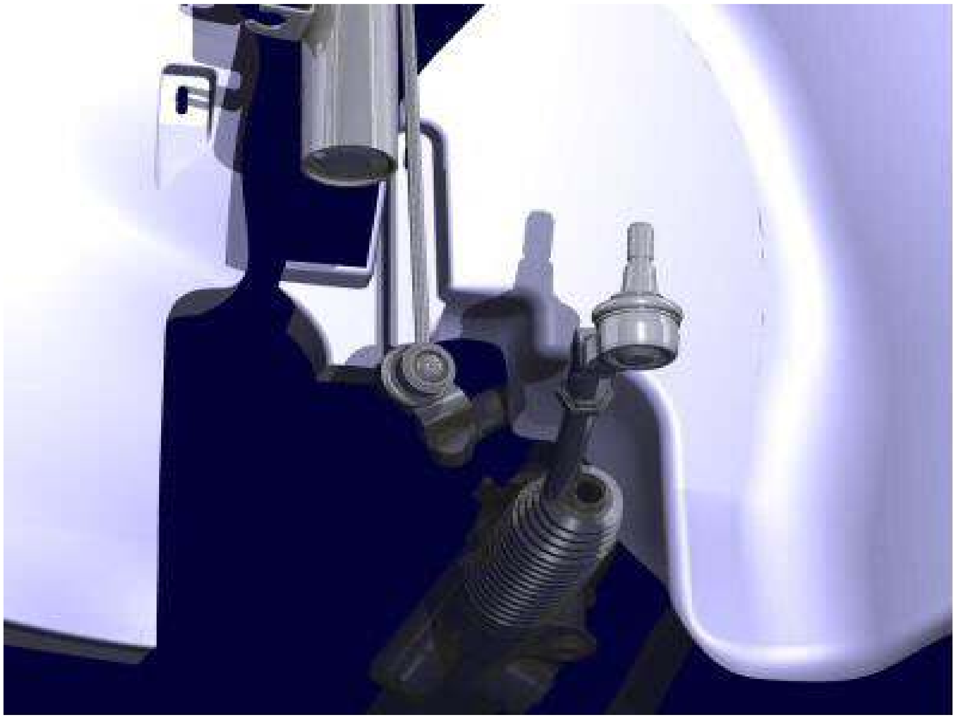


Figure 64 Picture of the “roof” over moving/rotating parts

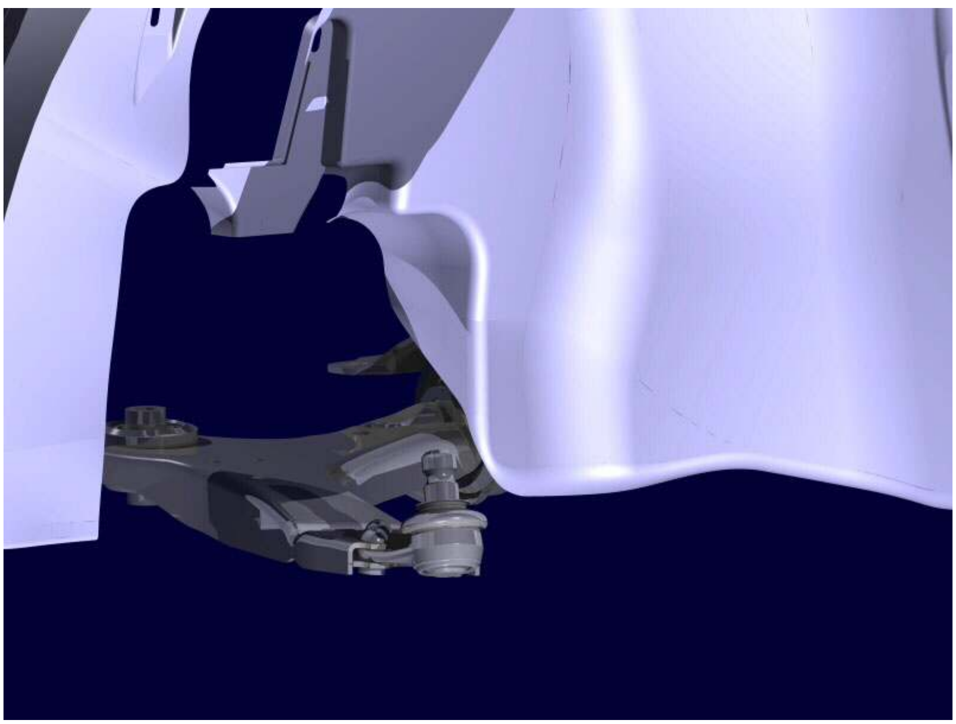


Figure 65 Cover of rear fixation of link arm

5.9.3 Gap

We extended the wheel arch liner and folded it under and around the sub frame and then fixated it to the under-shield.

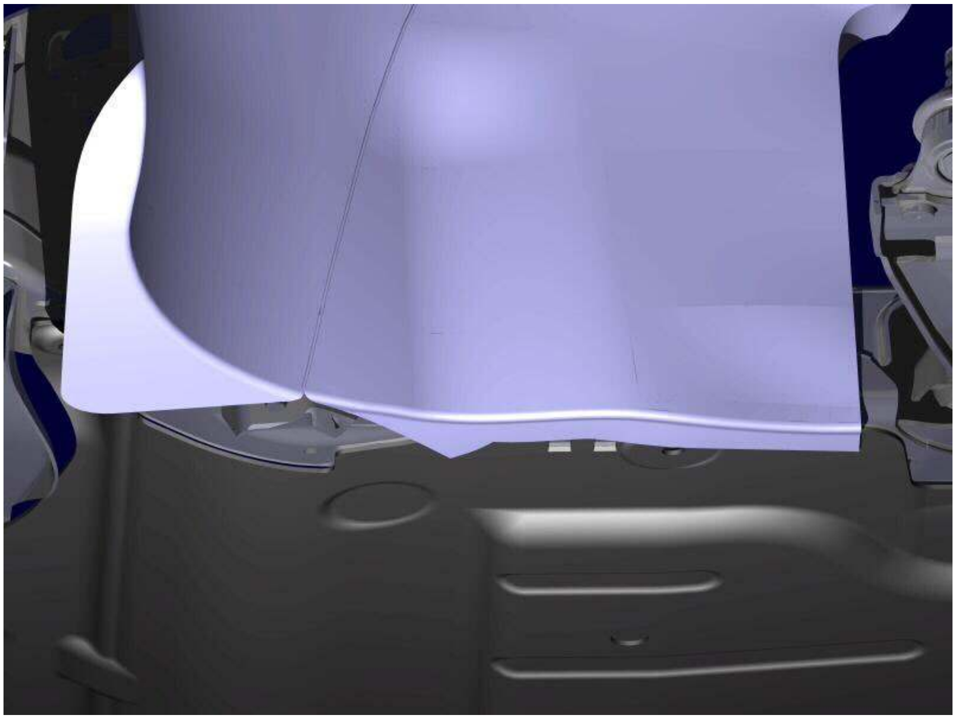


Figure 66 Picture of the covered gap, the dark grey part at the bottom of the picture is the under-shield

Solution to the problem with the movement between the wheel arch liner and the sub frame. The radius is designed to keep the wheel arch liner away from the sub frame when the two parts are moving.

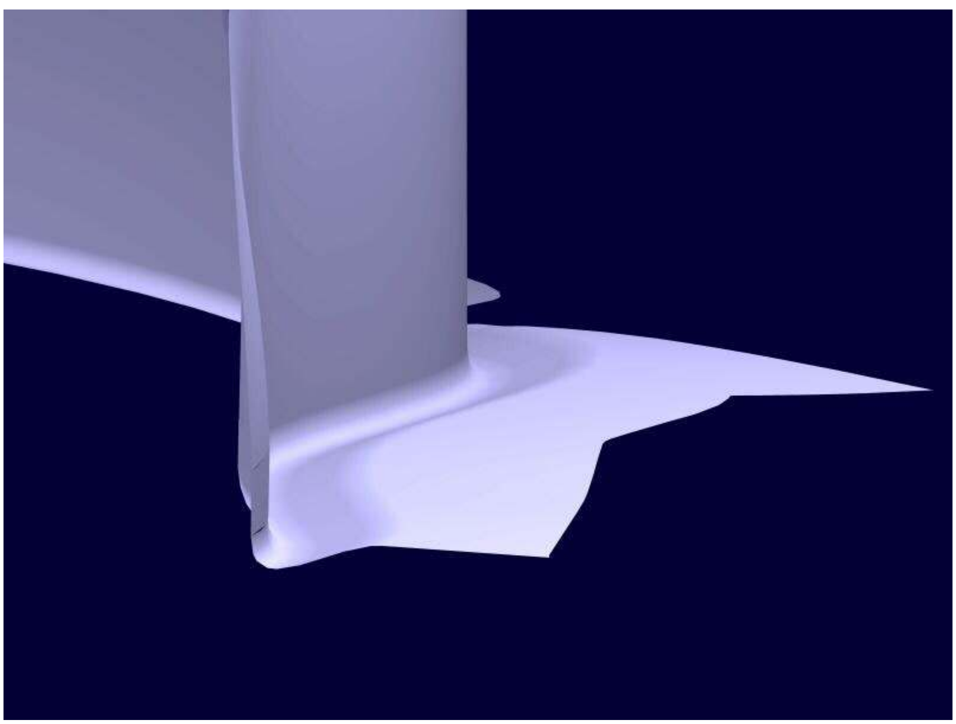


Figure 67 The special geometry for the solution with the relative movement between the under-shield and the wheel arch liner

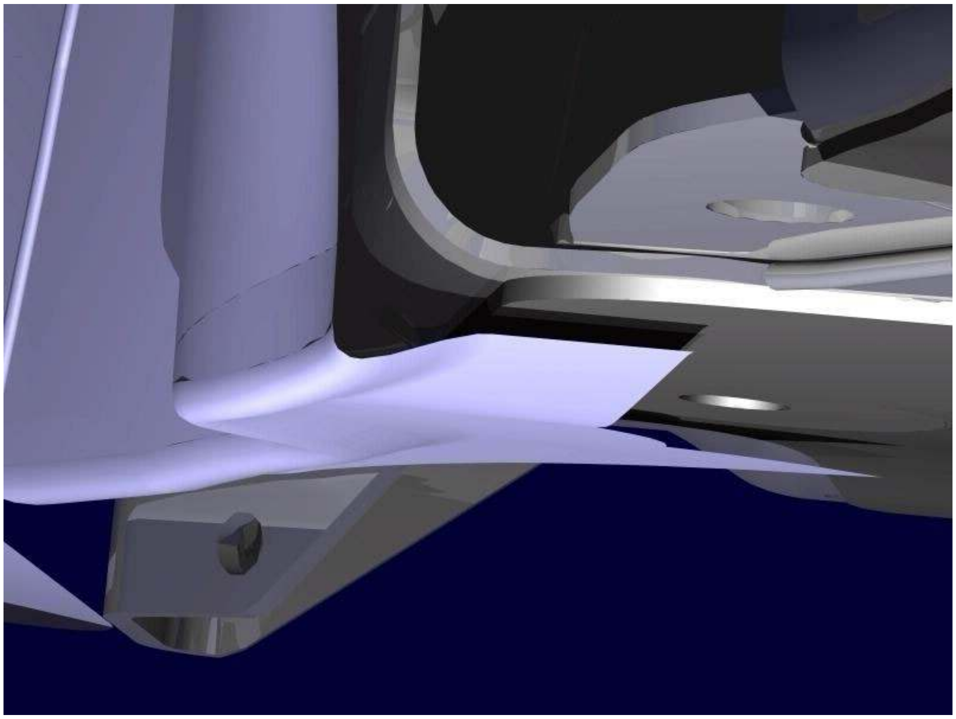


Figure 68 Picture of the distance between the wheel arch liner and the sub frame

5.9.4 Folding line and Splash shield

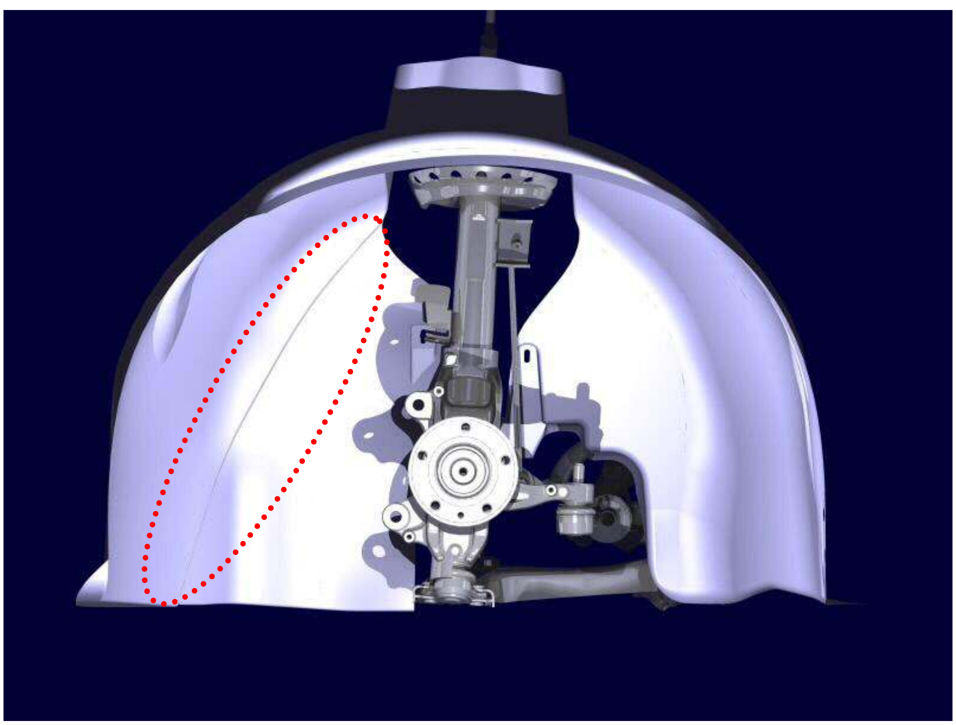


Figure 69 Picture of the folding line and the integrated splash shield at the front of the left front wheel arch liner

6 Discussion

The purpose with this master thesis has been to optimize the front wheel arch liner regarding material, geometry and cost. The weight of the wheel arch liner and the noise inside the coupe, are to be reduced considerably. It has also been of great importance to investigate the possibility to integrate the splash shield in the wheel arch liner to decrease the costs and simplify the assembly. Now at the end of the master thesis when we look at the result, we can establish that we have fulfilled the purpose and reached valuable conclusions.

The choice of method felt obvious to us but there are of course other alternatives which we could have used. No method guaranties however a good result and there is nothing that indicates that we would have chosen the wrong method.

At an early stage in the master thesis we carried out a thorough benchmarking by studying competitors and a large amount of patents and articles partly generated by the vehicle industry but also by other industries. As described earlier, a certain department at Volvo Group helped us with the search for articles and patents which may seem to have affected the search result but it is not likely due to the fact that the article and patent search were made in an impartial database. We as well as Volvo Cars have always, through out the entire work, strived for being impartial. The purpose with the master thesis has been to optimize the front wheel arch liner. That means aiming for nothing but the best. There is of course a risk that we might have missed an interesting article or a patent since we have used our own judgment when choosing the ones to study. But the large amount of studied articles and patents should cover the topic well. We established a high knowledge level within the subject and got a good picture of the state of the art. Competitors where mainly chosen after their technical level within the topic wheel arch liners. There is of course a risk that we have missed a valuable solution somewhere. An even more thorough benchmarking could perhaps include more of overall solutions and not only solutions connected to wheel arch liners.

After an extensive research it stood clear to us what kind of properties we wanted to test and also what materials we wanted to test. A majority of the tests ended up being written by our selves but often adapted after a corporate standard and according to our selves and not at least Volvo Cars, they were highly motivated. We have planed each test carefully and performed them with advanced and highly accurate equipment to reach a scientific level. Of course there is certain insecurity in each measurement and more material samples of each kind in every test are always better. We have therefore used as many material samples as possible in our tests, taken from the same area of the wheel arch liners. Since all wheel arch liners in our tests, except for the one in solid plastic, are thermoformed, the properties may differ to some extent. We have therefore consistently taken our material samples from the lower parts of the wheel arch liners where the material is not more stretched or harder compressed. The wheel arch liner made of solid plastic is injection molded and has therefore the same properties all over. In the case with contamination test II, we however considered the test and the results to be too far away from a scientific level and above all, the reality and therefore excluded it from the evaluation. It was simply a matter of a bad method and excluding the test did not affect the evaluation in a bad way. If anything, the other way around. After studies of already performed tests of splash shields we found no reason to perform tests on our own since the results stood clear. A splash shield considerably improves the contamination protection and there are no reasons why it should not be integrated in the wheel arch liner.

Regarding the geometry, we were only able to perform small changes which all together only composed one new concept. This is a result of the strict limitations in the wheel house area. If the development of the wheel arch liner would be given space at an earlier stage in a project several solutions could probably be generated and tried out. A procedure that most certainly also would generate a better solution. However, it felt quite obvious what we should aim for. As long as we kept the geometry within set limitations and enabled a suitable manufacturing and assembling, the result should bring a marked improvement. The fact that our wheel arch liner has grown in the matter of area, should not make the assembly more difficult thanks to a lighter material and the folding line. It is however impossible to predict exactly how our solution would work at all stages such as manufacturing, assembly and use. A truly proper evaluation requires testing of manufactured prototypes. Unfortunately it is not possible for us to have a prototype manufactured, tried out and evaluated. There is not room enough for this in our master thesis.

The evaluation used on the different material samples includes several personal assessments. First when evaluation criterions are chosen and weighted against each other and later on when grade scales are decided and different results are given grades. The result of these assessments would most certainly differ if someone else would have done the same work or if we would have asked for others opinions. It is however not the same as a better or worse result, just another result. This is not something that we can take into consideration but it is worth keeping in mind.

Before we begun the testing of the chosen material samples we were quite sure that the solid plastic would, out of a technical point of view, perform considerably worse in total than the other material samples. After putting together the results, it was however not the case. Many laminates did not reach a higher score than the solid plastic which is remarkably since these materials are far more expensive. The fact is that several car manufacturers, including Volvo Cars, pay a higher price for a material equal to solid plastic. To keep in mind though, is that the materials are good in different matters. Also, we did not expect a material to be that much better than other materials such as the penta laminate used on Mercedes Benz S-class turned out to be. The tendency of separation between layers in the penta laminate after the "wet" Charpy test, is not assessed as a serious problem at all even if it reduces the grade in that specific test. Despite this, the penta laminate is a fantastic material and a superior winner. Still, from a technical point of view. When costs are taken into consideration, the result of cost per point is more expected. Even though the prices on laminates are constantly decreasing, a wheel arch liner in solid plastic is still considerably cheaper. Hopefully there are possibilities to save money in other areas if a wheel arch liner as good as the one in a Mercedes Benz S-class would be used.

The fact is that we already can see that Volvo Cars are using parts of our result. Both results from the material tests and the developed geometry are implemented in the work of today. This strongly convinces us that our report will serve as a good basis for development of new solutions and future negotiations with different suppliers, but there is always room for further research and development. The optimal test of finding the optimal solution for a wheel arch liner would of course be to manufacture several wheel arch liners in different materials and with different geometry to assemble on actual Volvo cars and have tests carried out over a long time of period during all conceivable conditions. It would however cost a fortune and still be hard to find the perfect solution since several articles affect the very same properties as the wheel arch liner do for the entire car. Several articles should in other words be developed together at an early stage in each project.

7 Conclusion

At the beginning of this project none of us actually knew anything about wheel arch liners. Today, after twenty weeks with the topic, the situation is different. We can now establish that a wheel arch liner fulfills several crucial purposes on a car. For example noise absorption, contamination protection, corrosion protection etcetera. It also stands clear to us what properties Volvo Cars, and probably all car manufacturers give priority to at a development of a wheel arch liner. Namely noise properties, cost and contamination properties.

After all research and testing, the results shows that the penta laminate used for the wheel arch liner on Mercedes S-class is the absolute best material out of a technical point of view but the solid plastic used for the wheel arch liner on Volvo S40/V50 is the most economical material. That is to say that the plastic has the lowest cost per point in our tests. After assessment of the results in total we are however convinced that Volvo Cars should concentrate on further research of penta laminate equal to the one used on Mercedes S-class and open negotiations with different suppliers regarding a material of this kind. An obvious continuation of our tests that we recommend Volvo Cars, is to have prototypes of wheel arch liners manufactured in a penta laminate and tried out thoroughly on cars during long term tests.

As mentioned in chapter 1.1 Background, Volvo Cars is a part of the Premier Automotive Group (PAG), Ford's premium car division. We take for granted that Volvo Cars also claims to be a part of the premium car segment for the entire car industry and plan to stay there. A segment where highest quality and technical level definitely is required also in the future. This furthermore motivates a concentration on a penta laminate equal to the one used on Mercedes S-class and not only for front and rear wheel arch liners but also for other parts such as under-shields and under body panels. At least for Volvo Cars most exclusive models.

The tests and studies that Volvo Cars have performed earlier on splash shields clearly shows the use of the part and further research done by our selves, does not point at any problems with a splash shield integrated in the wheel arch liner. That is to say, provided that the geometry still enables a suitable manufacturing and assembling. It should also be possible to cover sensitive areas considerably more than what is being done today. To reach the best possible result regarding the geometry, we are of the opinion that Volvo Cars must study overall solutions and include parts such as the under-shield in the same development. A better wheel arch liner might very well admit removal of other parts which would result in a reduced number of parts to produce and assemble. That is to say, an opportunity to reduce costs and weight on other parts. This would defend the choice of a more expensive wheel arch liner.

To increase the chances of finding the best solution for a future wheel arch liner, Volvo Cars should start the developing of this at an earlier point in a project compared to what is done today. The possibilities are usually very limited because of other parts. An early cooperation between departments should lead to a better result of the development of several parts.

In connection to negotiations with suppliers we strongly recommend Volvo Cars to carry out research of their own. Partly to keep a high knowledge level on the topic to know what is possible to ask for and partly to be able to control and question a suppliers test results. We have experienced that suppliers not always carries out suitable tests which can lead to doubtful results. This is something Volvo Cars must be aware of.

Finally we recommend Volvo Cars to write a new proposal of a Technical Regulation for future wheel arch liners. These must include demands on the properties of the material used in the wheel arch liner. For example the highest allowed density, the highest acceptable weight increase due to water and dirt absorption, the lowest acceptable noise absorption and the highest acceptable splash noise level.

8 Sammanfattning

För ungefär tio år sedan kunde Volvo Cars se att biltillverkare började introducera bakre hjulhus tillverkade av ”non-woven” fibrer eller någon form av laminat vilket idag är högst vanligt. Volvo Cars har också sett att konkurrenter nu börjar utveckla främre hjulhus mer och mer och räknar med en utveckling liknande den för bakre hjulhus. Detta är anledningen till att vi har fått uppgiften att optimera det främre hjulhuset.

För utveckling av mekaniska produkter så som bildelar, är en diskursiv metod mest lämpad att följa. Till exempel systematisk konceptutveckling som vi har valt att använda i vårt arbete.

Sett ur ett tekniskt perspektiv, visar våra resultat att pentalaminatet som används för hjulhusen på Mercedes Benz S-klass, är det överlägset bästa materialet. Tyvärr ar det ganska dyrt vilket naturligtvis påverkar dess resultat negativt när hänsyn tas till kostnader. När vi även ser till kostnaderna, är faktiskt den rena plasten mycket ekonomisk. Efter bedömning av det totala resultatet, är vi helt övertygade om att Volvo Cars borde koncentrera sig på fortsatta undersökningar av pentalaminat och inleda förhandlingar med olika underleverantörer angående material av denna typ.

Angående geometrin, visar Volvo Cars’ sedan tidigare genomförda tester och studier att en splash shield fyller en viktig funktion och vidare undersökningar genomförda av oss själva pekar inte på några problem med en i hjulhuset integrerad splash shield.

<u>Nyckelord:</u> Volvo Cars, innerhjulhus, laminat

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Appendix 1, Technical Regulation

1. Function
   - What is the purpose with the product, which is its task?
   - Shall there be any extra functions?
   - Etc.

2. Function determining properties
   - What performance shall the product fulfill?
   - Does manufacturing, assembling, distribution or use affect size or weight of the product?
   - Are there any secondary outputs?
   - What dimensions shall the product have?
   - Etc.

3. Properties over time
   - In what environment will the product be used?
   - How often will the product be in use?
   - Life length?
   - Is maintenance necessary?
   - Which parts might have to be replaced?
   - Which parts have to be reachable?
   - Shall there be an upgrading of the part in the future?
   - Are there any restrictions, for example energy consumption?
   - Etc.

4. Manufacturing properties
   - Shall the product be produced with existing machines/tools?
   - Is an investment in new machines profitable?
   - Shall the manufacturing take place at a supplier?
   - Shall the product be tried out and what does that mean?
   - Does the product need to be tried out after manufacturing?
   - When does the production start?
   - Etc.

5. Distribution properties
   - What kinds of transports are necessary during and after manufacturing the product?
   - Shall the product be stored, if so what demands are there on the product?
   - Does the product demand wrapping and what is the purpose with it?
   - Shall the product be assembled/installed after delivery (if so by whom)?
   - Etc.

6. Delivery and planning properties
   - How many products should be manufactured?
   - Shall the manufacturing be continues or in batches
   - Etc.

7. Safety/ergonomic properties
   - Which properties shall the product have to be ergonomic?
   - What properties are demanded to make the product safe to use?

- Are there any secondary outputs that can affect the user?
- Are there any demands on special devises so that the user does not risk getting hurt?
- Etc.

8. Aesthetical properties
   - What demands do the customers/users have?
   - Shall the product be design so it matches the companies other products, what does this mean?
   - Shall there be taken considerations concerning trend and fashion of the product?
   - Etc.

9. Law properties
   - Which laws must the product follow?
   - For what type of indictable or unintentional accidents can the company be hold responsible for?
   - What standards must the product follow?
   - Does the product make patent infringements and how can this be avoided?
   - Etc.

10. Economical properties
    - What are the allowed manufactory costs?
    - What are the allowed operation costs?
    - Sales price?
    - Scrap/disassemble costs?
    - Etc.

11. Recycling and scrap properties
    - Shall subsystems/components/materials be recycled?
    - Shall the product be separated in different materials and/or parts before scraping?
    - Shall the product be disassembled and what demands does this make on the product?
    - Etc.

12. Ecological properties
    - What types of materials shall be avoided concerning negative environment affects during manufacturing, usage or scraping?
    - Etc.

Appendix 2, Stiffness test, raw data

Alfa Romeo 166

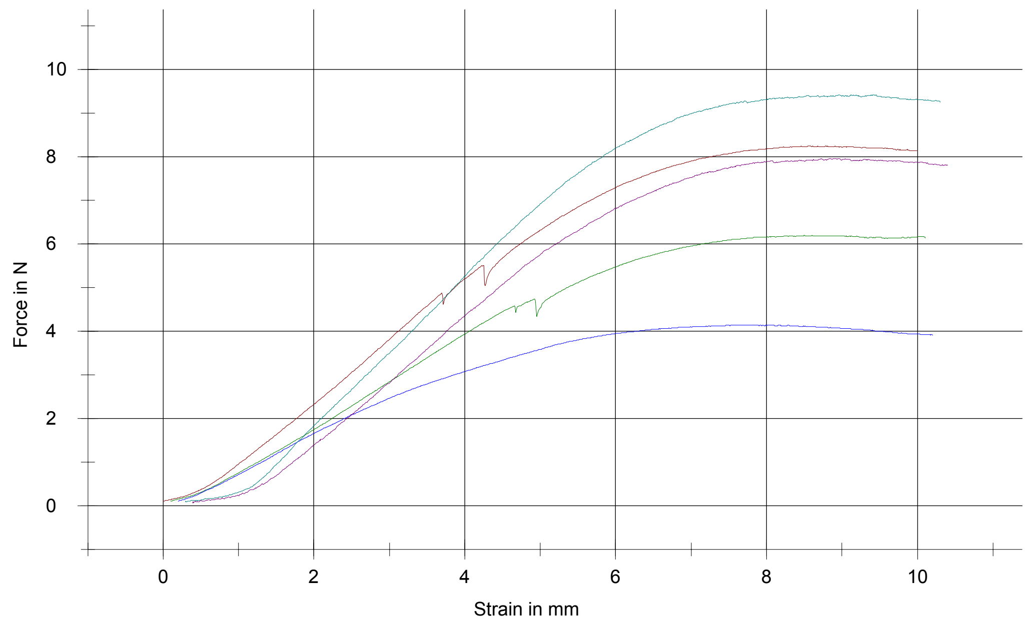

Figure 70 Raw data from the stiffness test, Alfa Romeo 166

Audi A6 TDI

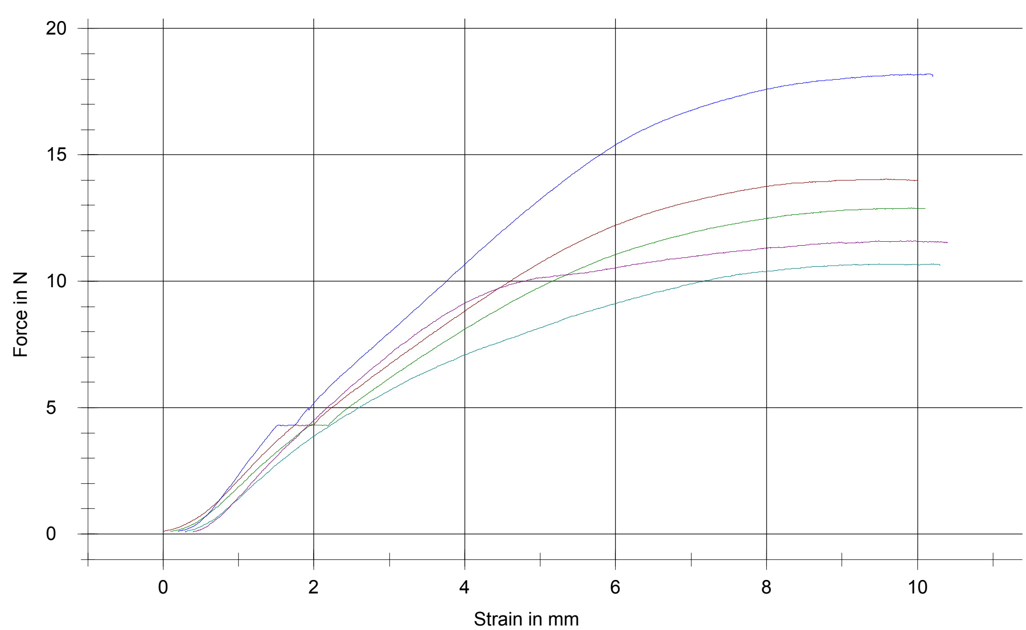

Figure 71 Raw data from the stiffness test, Audi A6 TDI

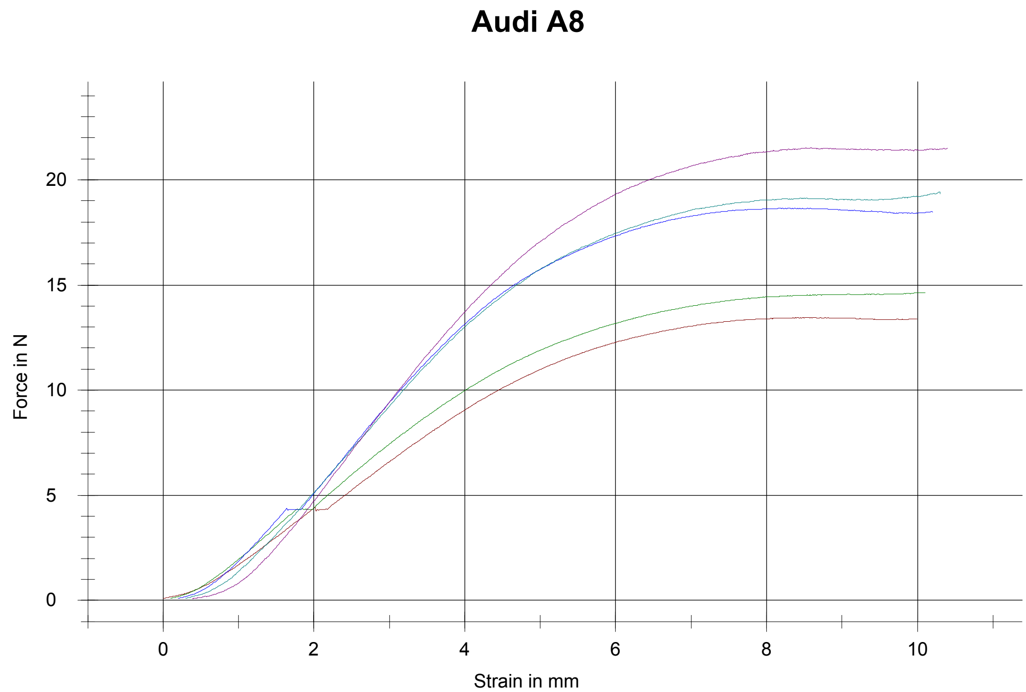

Figure 72 Raw data from the stiffness test, Audi A8

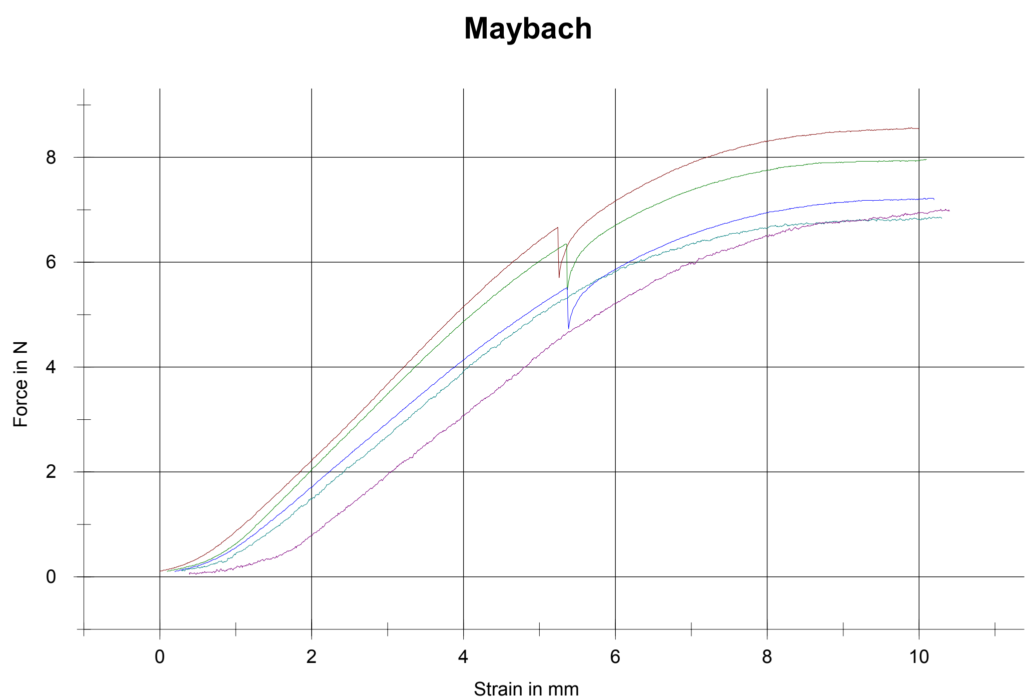

Figure 73 Raw data from the stiffness test, Maybach

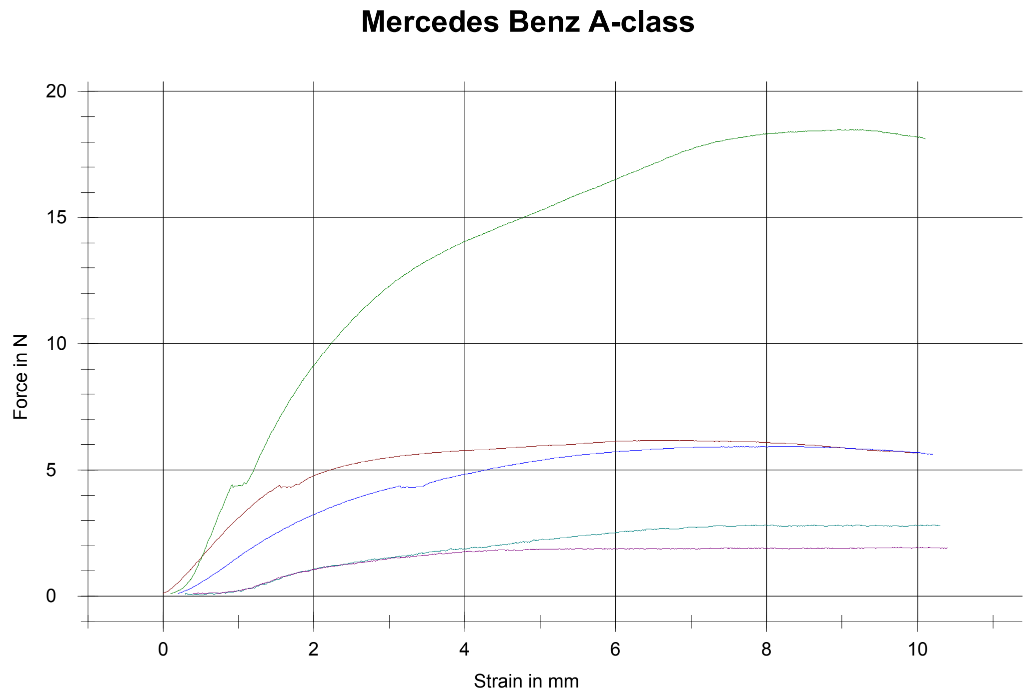

Figure 74 Raw data from the stiffness test, Mercedes Benz A-class

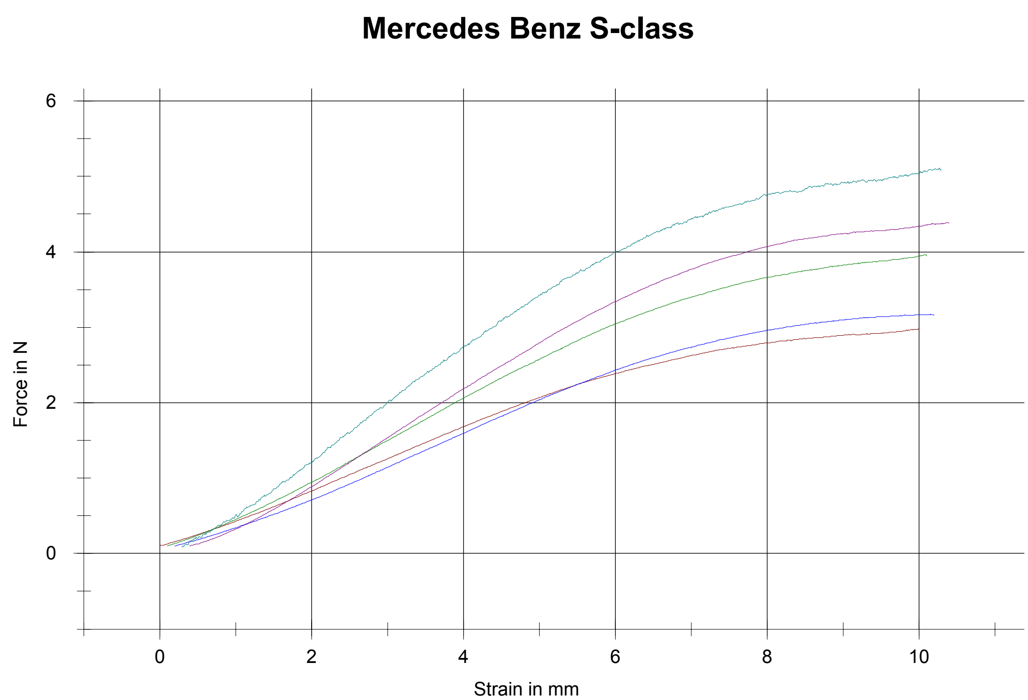

Figure 75 Raw data from the stiffness test, Mercedes Benz S-class

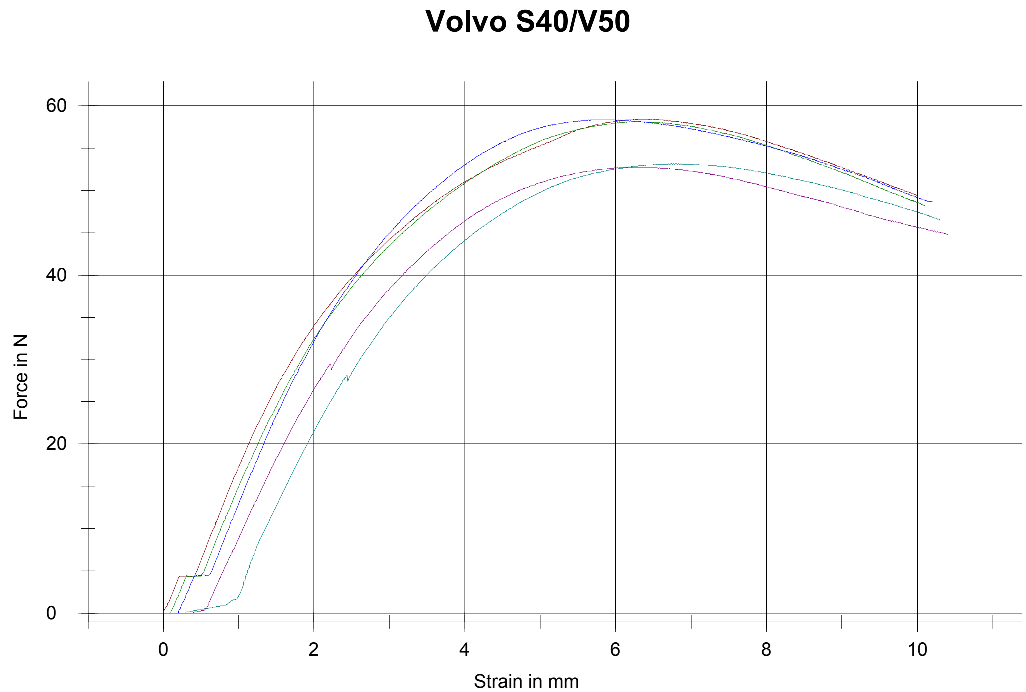

Figure 76 Raw data from the stiffness test, Volvo S40/V50

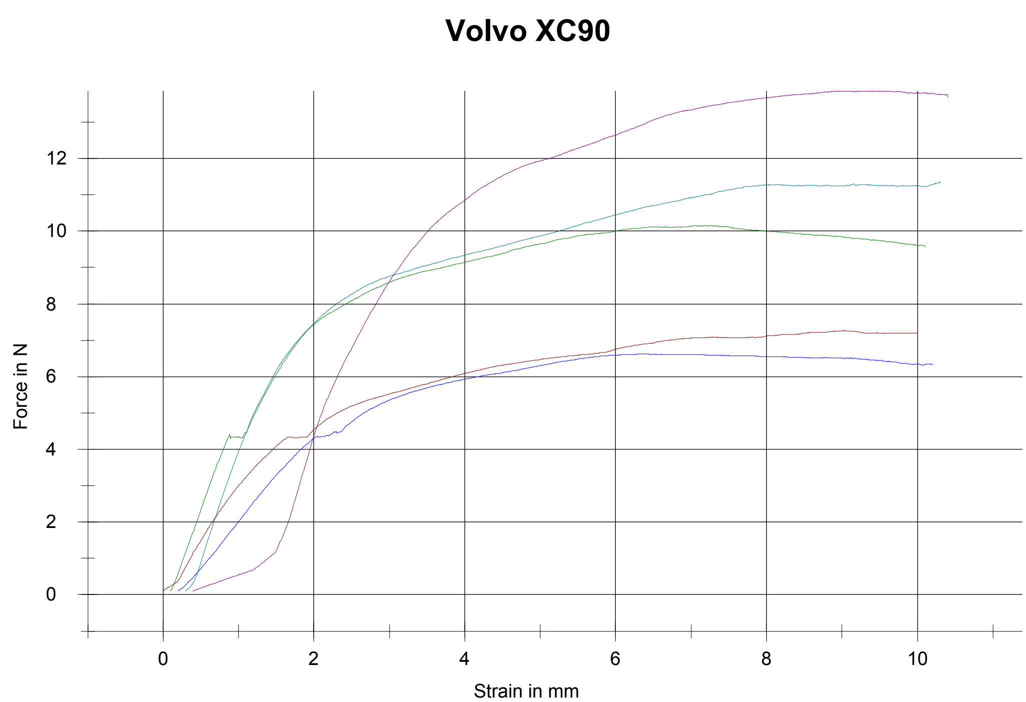

Figure 77 Raw data from the stiffness test, Volvo XC90

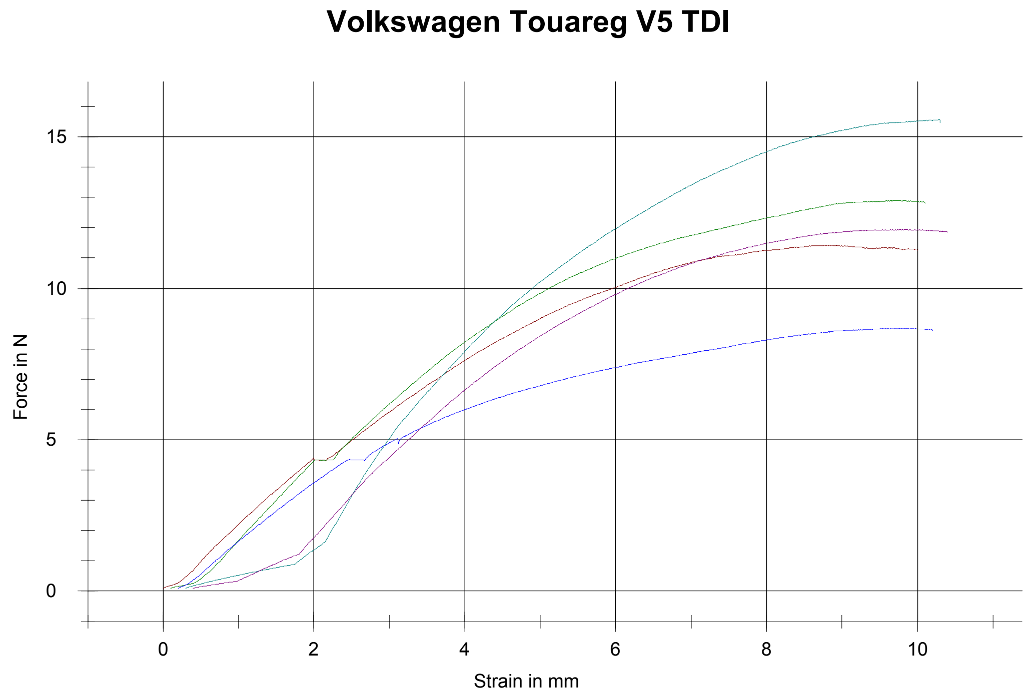

Figure 78 Raw data from the stiffness test, Volkswagen Touareg V5 TDI

Appendix 3, Noise absorption test, raw data

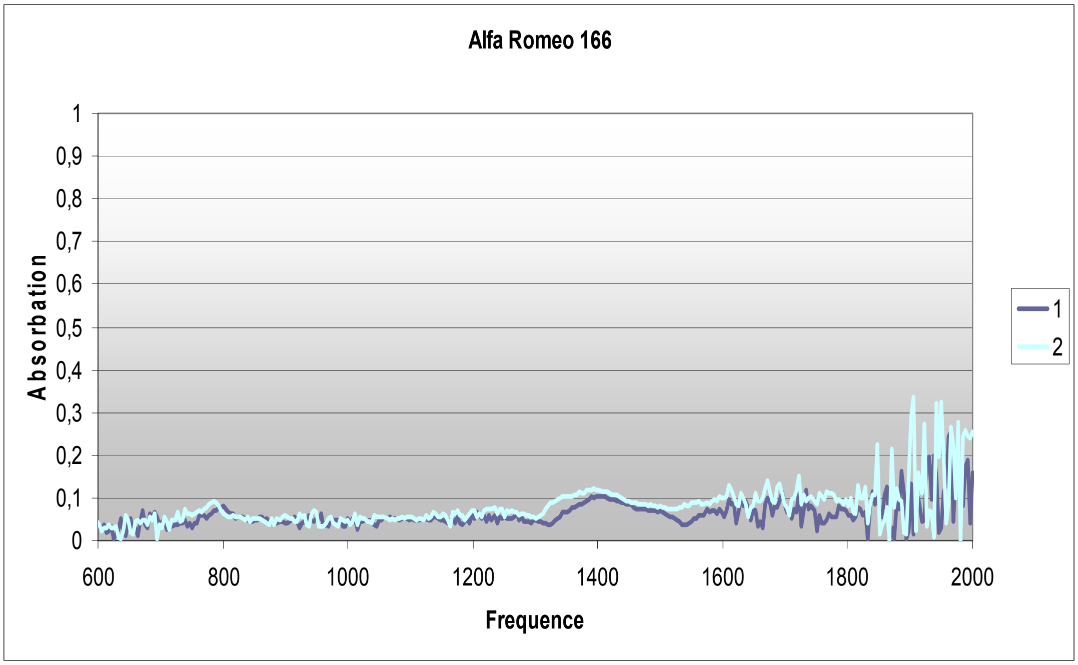

Figure 79 Raw data from the noise absorption test, Alfa Romeo 166

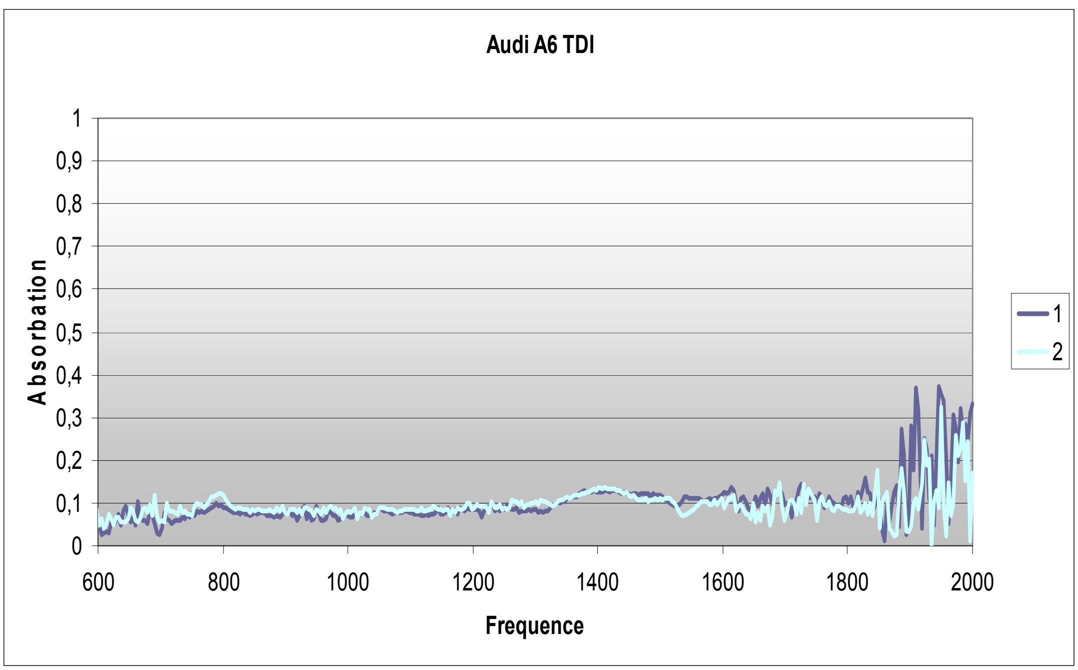

Figure 80 Raw data from the noise absorption test, Audi A6 TDI

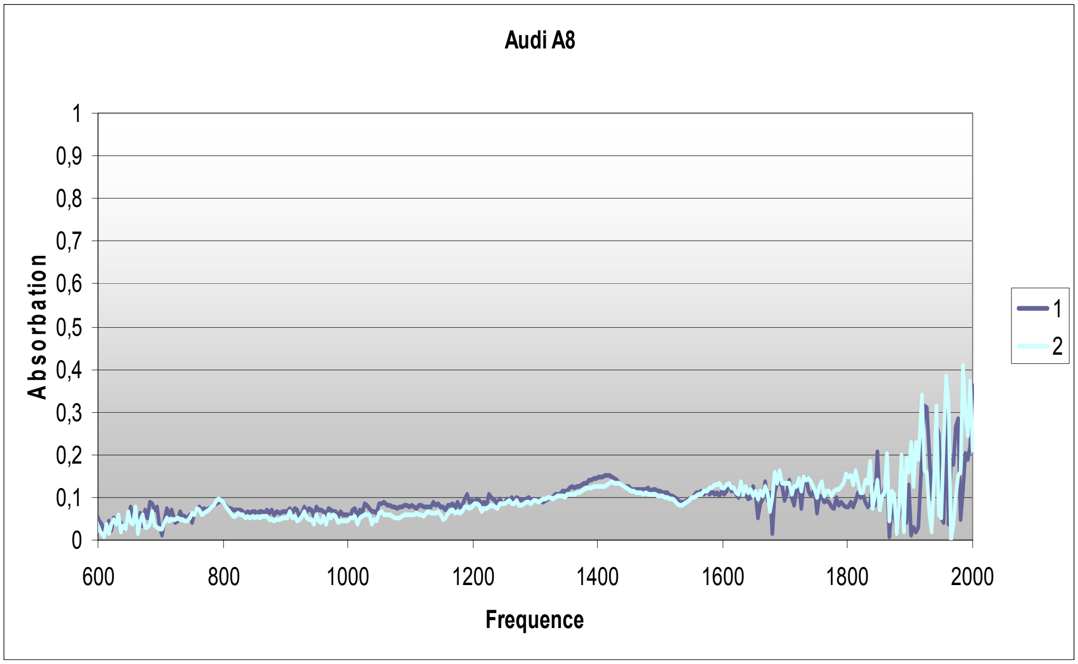

Figure 81 Raw data from the noise absorption test, Audi A8

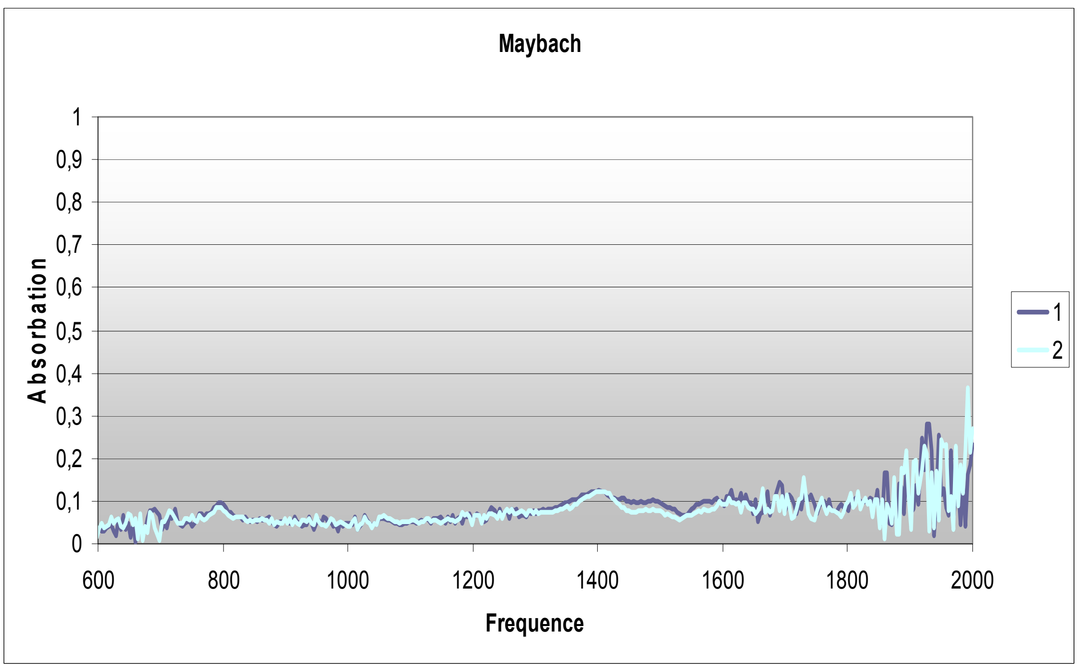

Figure 82 Raw data from the noise absorption test, Maybach

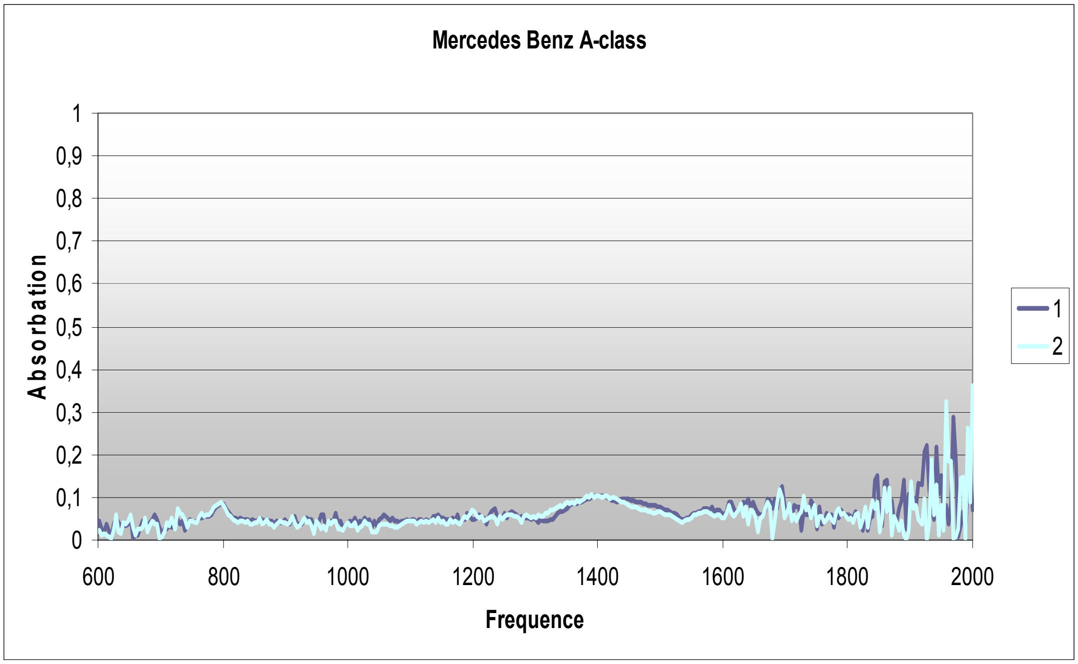

Figure 83 Raw data from the noise absorption test, Mercedes Benz A-class

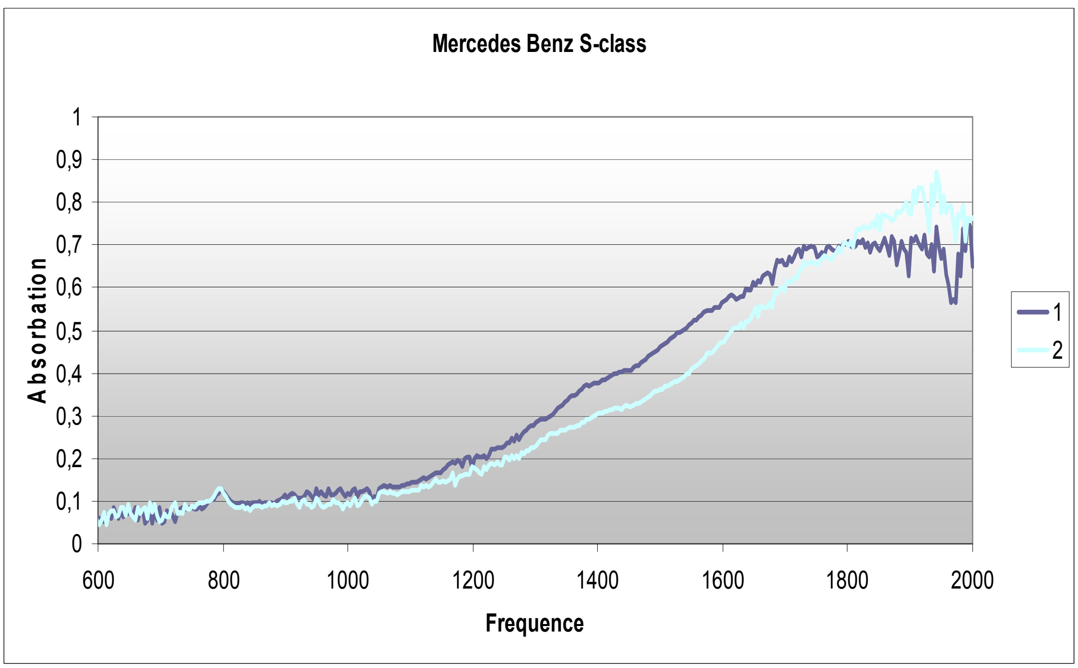

Figure 84 Raw data from the noise absorption test, Mercedes Benz S-class

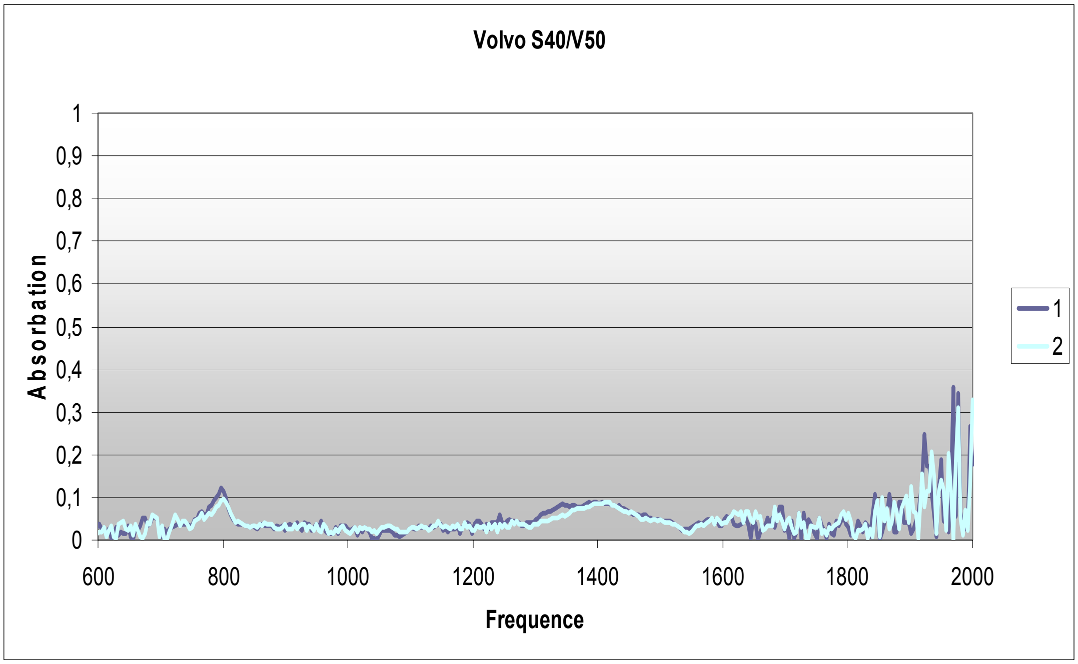

Figure 85 Raw data from the noise absorption test, Volvo S40/V50

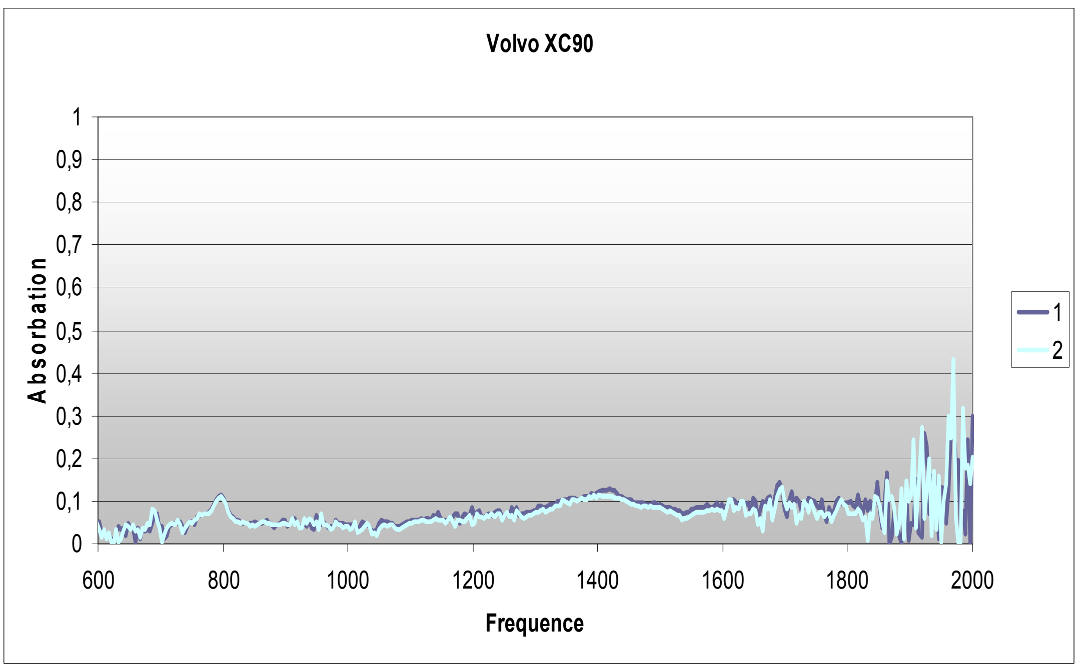

Figure 86 Raw data from the noise absorption test, Volvo XC90

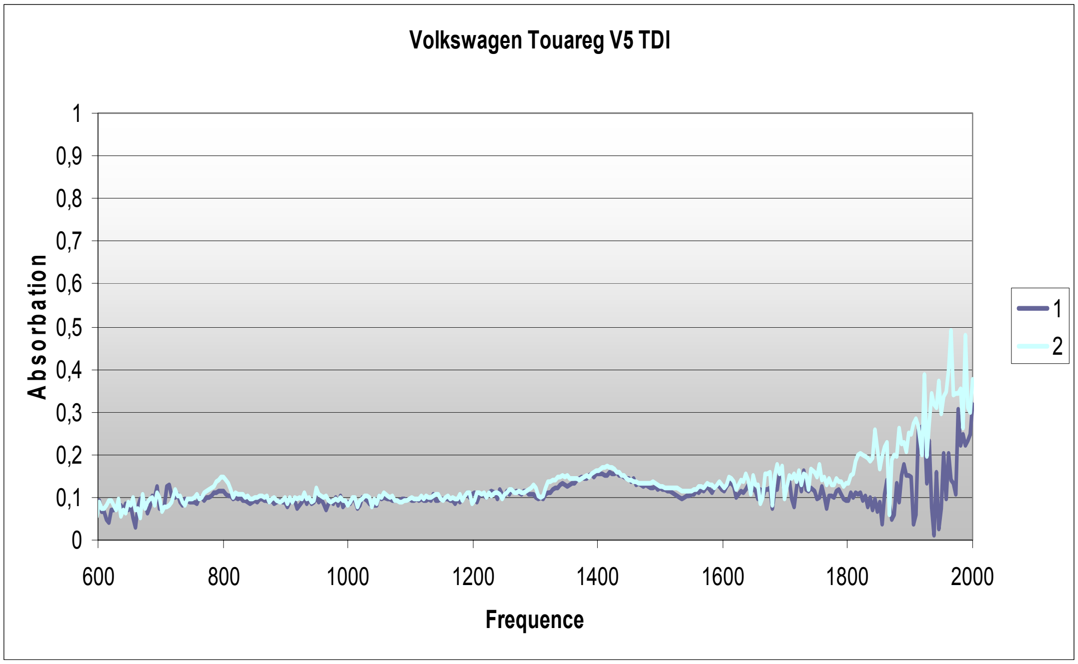

Figure 87 Raw data from the noise absorption test, Volkswagen Touareg V5 TDI