UNIVERISDAD PANAMERICANA
FACULTAD DE INGENIERÍA
Con estudios incorporados a la
Secretaría de Educación Pública

“NOISE PROPAGATION IN EVAP SYSTEM”

CASO PRÁCTICO

QUE PARA OBTENER EL TÍTULO DE
MAESTRÍA EN INGENIERÍA

PRESENTA
FERNANDO SADA GARIBAY

DIRECTOR DE TESIS:
ERNESTO L. RODRÍGUEZ GONZÁLEZ

MÉXICO, D.F. 2022

Summary

The purpose of the project was to use the Design for Six Sigma methodology to find the best solution to mitigate a noise in the EVAP system caused by the purge valve and develop new design best practices for future applications in the vehicles of a well knows automotive company which name will not be disclosed.

The EVAP system purge noise is a well-known problem cause by the pulsations of the cyclic nature of the purge valve, and different technologies have been developed to address it. The DFSS methodology allows us to evaluate several of them at the same time while being very efficient with the resources.

After defining the Ideal Function, the Input Strategy, the Noise Strategy, the Designs to be used, Laying out the Experiment, Proving the Experimental Strategy, Completing the Experiment and finally Analyzing the Experiment results, the team was able to identify the most important factors and characteristics that allow for a more robust system against the noises that cause variability in the system.

By using one of the expansion chambers closer to the canister the noise is mitigated below the point where the customer can hear it. Also, other alternatives were identified to allow for more flexibility when it comes about packaging the best solution on the vehicle.

Table of Contents

Tables, Figures and Formulas References

Chapter 1: Background

This project was performed to address the needs of an automotive manufacturing corporation which I will be referring to as “THE COMPANY” due to internal policies.

With the automotive industry being one of the most important in Mexico, THE COMPANY has different manufacturing locations in different states. There are also other manufacturing locations across the world, however one of the biggest tech centers for THE COMPANY lies in United States, where different laboratories and facilities can be found.

Within those laboratories, THE COMPANY has an NVH lab. NVH stands for Noise, Harshness and Vibration and is the group in charge of evaluating the customer perception of those characteristics on a vehicle, and this lab is equipped with temperature chambers, sounds-proof rooms and all the necessary tools to perform their assessments.

The team in charge of the development of the vehicles is the Product Development group. This team works with designers or does the designs themselves. They also work very closely with suppliers to choose the best solutions for THE COMPANY needs. Additionally, they work with the same suppliers to validate their solutions; this way it is verified that the components meet the requirements and standards with certain levels of confidence. Supporting the assembly plants when new vehicles are launched to make sure all the new components can be assembled without any problems is another one of the everyday tasks the group performs, as well as addressing warranty claims and complaints from the customers when changes need to be made to guarantee the reported problems won't happen again in the life of the vehicle.

Chapter 2: Diagnosis of the situation

There are different ways in which complains with the vehicle are brought into the team's attention. The most usual ones are through warranty claims directly from the customer for issues that aren't caught prior to launching the platform, or through other parties, such as the Reliability group which can drive vehicles during the development phase prior to launch.

The Reliability fleet is a group of vehicles that are driven by an external company to accumulate miles on cars that have been built on some of the early build phases, months before production begins. During these early build phases, a lot of vehicles are assembled at different levels of validation and readiness of both the components and the plant, to be used in several different evaluation runs. These evaluations range from making sure that the assembly plants have all the process and tools ready, to accumulating real driving miles on vehicles, as most of the validation that had been run by that time was done either on a component or a system level, but not on a vehicle level.

The group of people driving are usually the first ones to detect problems that are only present at a vehicle level and not just component or system level. As such, they can raise their concerns whenever something happens on a vehicle. Their claims cover a very wide range. From noises they hear while driving, the feeling they get from being behind the wheel, if any of the surfaces on the vehicle is too reflective and annoying as it mirrors the sunlight into their eyes, or mechanical problems such as components not working as they should, engine warnings on the panel, etc.

When a concern is raised, the Product Development team must act accordingly to provide an explanation to the problem, find the root cause, propose a containment, and then implement a permanent action. In the case of the first platform that presented the noise concern, the team was able to identify the noise quickly as it is very characteristic of the purge valve. It was through the release of a big expansion chamber within the evaporative system that the noise was brought down to an acceptable level.

For anyone who has ever been inside a running car it is very clear that there are many different noises. From the wheels on the asphalt, the engine roar or the suspension when hitting a pothole. However, this particular noise had to do with the purge system.

To go deeper into the definition of the problem I will explain how the fuels and evaporative system of any vehicle works.

Gasoline is a very volatile compound made of different hydrocarbon chains. As a consequence, it evaporates constantly. Some factors can accelerate or slow down this process, but the main contributors are temperature, pressure, and the internal composition of the gasoline and how likely it is to evaporate, and this characteristic is measured through the Reid Vapor Pressure (RVP).

At lower pressures and higher temperatures, the gasoline evaporates more quickly than at colder temperature and lower pressures. As for the gasoline composition, since the weather conditions in the United States varies significantly through the year based each state, during summer a gasoline with a lower RVP is used to try to have as little evaporation as possible, however during winter a higher RVP blend of fuel is used, otherwise it gets harder for gasoline to become atomized in the injectors and starting a car in very low temperatures would be nearly impossible.

The gasoline is held in a reservoir called fuel tank which also contains a pump that sends the fluid into the engine, directly to the injectors rail where then it is atomized and burned in the engine as part of the stoichiometric mixture. See Figure 1 - EVAP System Diagram. Self-made

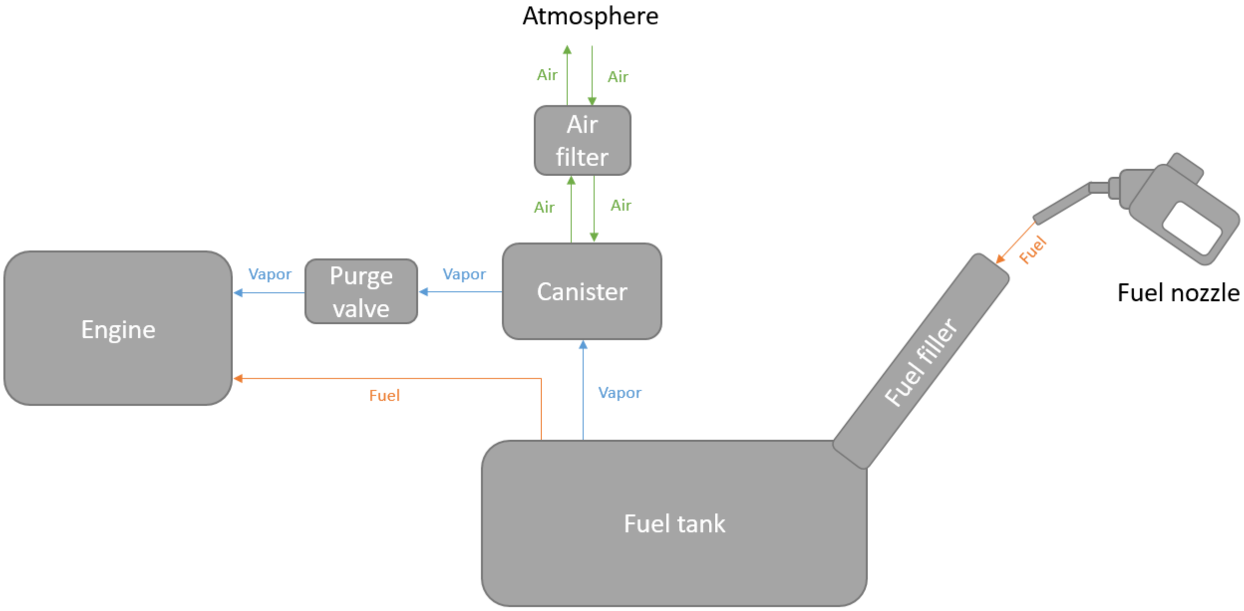


Figure 1 - EVAP System Diagram. Self-made

As mentioned previously, that gasoline within the fuel tank is evaporating all the time, and if the vapors don’t have anywhere to go, then we would have a constant increase of pressure of the tank until it would eventually begin leaking through one of the connections, or as a worst-case scenario, explode.

As an alternative, the car manufacturers could release those vapors into the ambient, but that would end up polluting the atmosphere, so it is not feasible. The most logical thing to do is burn the vapors in the engine, because at the end of the day, it is still gasoline.

To do so the vehicles have the evaporative system, which runs in parallel to the fuel system, but with some minor differences. The vapors from the fuel tank are transferred into a canister which contains pellets of activated carbon which have a very high porosity and therefore a very high surface area, and their purpose is to filter the vapors from the tank and trap all the hydrocarbons from the gasoline. See Figure 2 - Carbon Canister. Self-made This way the car can have the system open to the atmosphere for it to breath without releasing chemicals into the ambient.

The hydrocarbons that are being held into the canister will then be pulled into the engine due to the vacuum that it draws. The evaporative system has a Purge valve, a solenoid used to regulate the vacuum that the canister is exposed to, as the engine is drawing it all the time. Since the process of having the correct stoichiometric mixture is very important, it is imperative that the vapors are drawn into the engine at the right time.

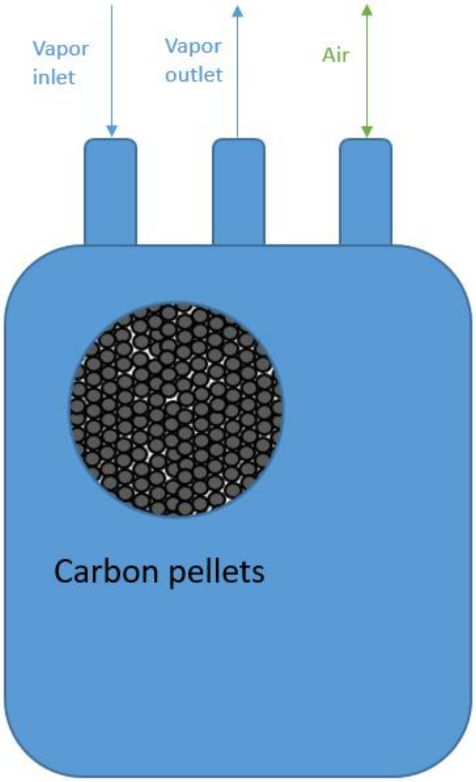
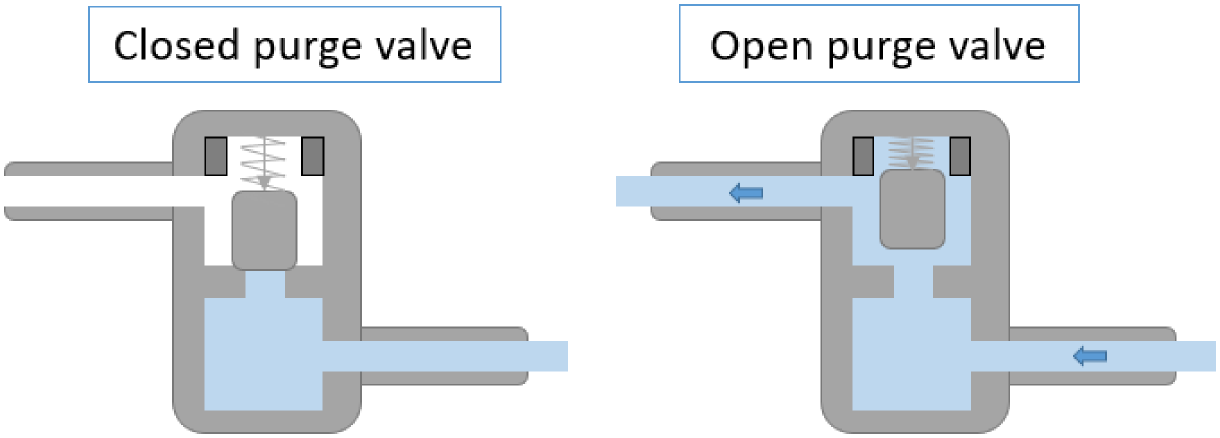


Figure 2 - Carbon Canister. Self-made

Under specific conditions, the Engine Control Module (ECU) commands the Purge valve to open in what is called Duty Cycle Purge, and this allows the vacuum to draw the vapors from the canister into the engine.

The purge valve is controlled through Pulse Width Modulation at a high frequency. It is expected to have more than two hundred million activations of the purge valve solenoid through the life of the vehicle for example. It is due to this purge valve and its frequency that air pulsations are sent through the vapor lines in the system. See Figure 3 - Purge Valve Operation. Self-made



The purge valve is normally closed; therefore, the vapors can’t flow even though the engine is always drawing vacuum. The valve solenoid must be activated to allow flow.

Figure 3 - Purge Valve Operation. Self-made

Said pulsations travel through the system until they reach the canister where the shell works as a resonating chamber and makes a noise that can be heard by the customer. The customers often describe this noise as a “helicopter” noise coming from the rear of their vehicle.

One of the main reasons that this problem has become more prominent through the years is the tighter emissions and purging targets that are stablished by the government in different countries. Among the strictest countries when it comes to said regulations is United States. There are two main entities that are responsible to regulate the emissions of the automobile vehicles. The first one is the Environmental Protection Agency (EPA) which is part of the federal government. The other one is called California Air Resources Board, and as the name suggests, it isn’t federal but belongs to the state of California.

Each state is free to stablish their own emissions restrictions and requirements as long as they fall within the federal requirements. CARB requirements are more severe than EPA's, since California's geographic conditions promote higher pollution concentration in that area, so they keep tighter regulations to reduce ambient contamination.

Since more and more states tend to adopt CARB's requirements, automotive manufacturers will often design the vehicles to meet those regulations, and as they are becoming harsher every couple of years, then the way that vehicles are design and calibrated change to meet said requirements.

To meet the lower emissions and higher efficiency requirements the automakers produce systems that perform better when it comes to trapping the hydrocarbons within the system, therefore more purging is necessary and as a consequence, the frequency at which the purge valve is activated also increases. This means that as the years have gone by, it has become more common to run into the problem of the purge valve being audible.

Also since the engine is the main source of noise on a vehicle and the technological advancements have allowed more silent engines, then it is easier to pick up noises that were concealed by the engine before.

Because of those two factors, it is more common for newer platforms to have that noise complaint and as such, THE COMPANY has tried to mitigate the issue with different technologies using a trial-and-error basis.

Since the noise is not detectable during the development of the vehicle because it involves the interaction of all the components, it is very hard to design away from it during early development stages. If a change is needed in the later stages of development, then it becomes harder and more expensive to address.

As a conclusion for the diagnosis, the following key points where stablished:

- **Hypothesis:** If the team tests the different countermeasures used to mitigate purge noises in the EVAP system, then it will be possible to identify which one performs better and under what conditions.

- **General objective:** Identify which of the countermeasures to the purge noise that are already in production perform better when it comes to mitigate the noise of the purge system while being subjected to the conditions that are considered to be the worst.

- **Specific objectives:**
    1. Determine the best measurement methodology to be able to quantify the

performance of each countermeasure in an ambient that is both repeatable and recordable.

2. Using the available resources within THE COMPANY and its various labs, measure the performance level of the different countermeasures.

3. Identify the critical conditions that have a direct correlation with the noise propagation test the different countermeasures under those specific conditions.

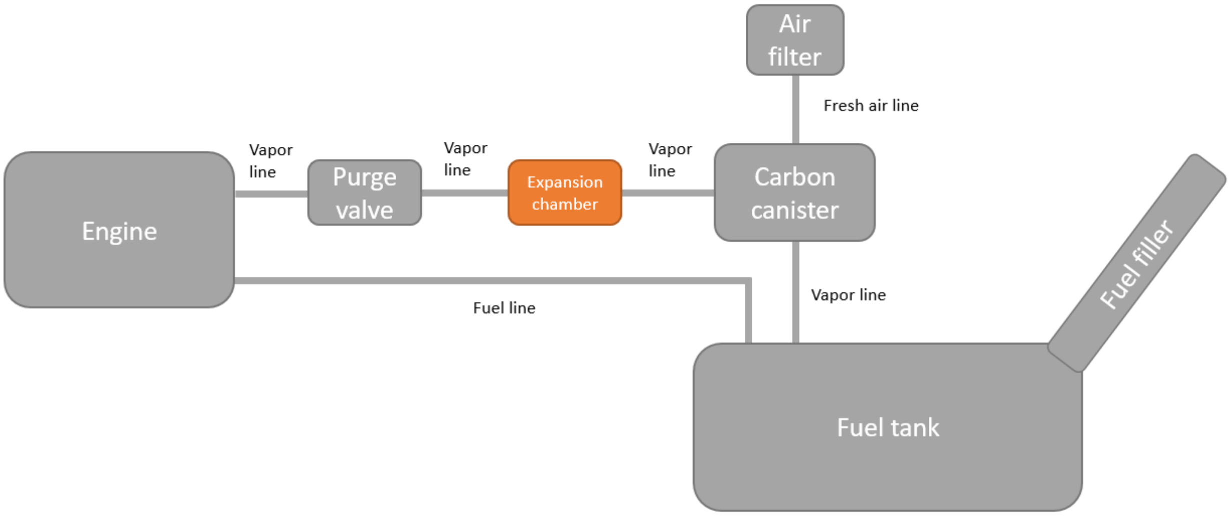


Figure 4 - Countermeasure Location. Self-made

Chapter 3: Theoretical Framework

Within THE COMPANY, there are various methodologies to approach different problems. Some are reactive in the sense that once a problem has occurred, they focus on tools to find the root cause to later address the correct problem and not attacking just a symptom. There are also other methodologies that are proactive, which means that they focus on the development process to guarantee that problems won't be found further down the life of the product.

Some of the most common methodologies used within THE COMPANY are the following:

a. **Design for Six Sigm**a – A process used to design and develop new components or modify existing one to achieve certain level of robustness and assure customer expectations are met.

   An example of this methodology being applied is designing a new fuel filler cap with acceptable closing efforts in order guarantee customers won't struggle at the moment of closing the cap, or that they won’t close it incorrectly by mistake. (A wrongly closed fuel cap will trigger a Check Engine Light on the dash panel).

Quoting Creveling, Slutsky and Antis in their book Design for Six Sigma in Technology and Product Development: “DFSS does not replace current engineering methods, nor does it relieve an organization of the need to pursue excellence in engineering and product development. DFSS adds another dimension to product development, called Critical Parameter Management (CPM).” (Mader, 2002, p82).

This approach focuses on the customer, and consequently, on the design’s functions, parameters and critical characteristics that help to fulfill the customer’s needs. Additionally, the concept of DFSS has been evolving through the years, particularly considering it has been around since the 1980’s. (Cudney, 2016).

We can also find the following definitions in literature:

- “While Six Sigma helps fix what is broken [...] Design for Six Sigma helps to design things that don’t break in the first place, things that do more and cost less” (Chowdhury, 2002a, b).

- “The term ‘Six Sigma’ in the context of DFSS can be defined as the level at which design vulnerabilities are not effective or minimal. Generally, two major design vulnerabilities may affect the quality of a design:
    - Conceptual vulnerabilities that are established because of the violation of design axioms and principles.
    - Operational vulnerabilities due to the lack of robustness in the use environment. Elimination or reduction of operational vulnerabilities is the objective of [...] Six Sigma” (Yang and El-Haik, 2003).

- “DFSS has three major components: product line management, design and new product development project management, and the Six Sigma toolkit (define-measure-analyze-design-verify (DMADV)) that is applied in the product creation process. The definition of DFSS that we will use is: *Design for Six Sigma is a process to define, design and deliver innovative products that provide competitively attractive value to customers in a manner that achieves the critical-to-quality characteristics for all the significant functions.”* (Watson, 2005).

b. **Reactive** – A process used to find the root cause of a problem on an existing part or system. The main methodologies used are Red X by the Shainin Company and the Kepner-Tregoe method.

An example of this process is finding the root cause of excessive closing effort on a fuel filler cap on certain platform and model year that the customers have been complaining for only the last four months but not before.

Dorian Shainin developed a series of strategies and tools that are widely used in the automotive industry. (Steiner, 2008, p37). This methodology, also called Statistical Engineering, emphasizes the use of statistical tools to reach a certain level of confidence when searching for what could be causing a problem. (Trimarjoko, 2019, p2421).

The tools most used for problem solving under the Shainin System are the Solution Tree (Shainin, 2008, p42), the Multi-vari (Shainin, 2007, p1800), Isoplot and Component Search (Steiner, 2008, p6). The focus is on doing "dictionary splits" which makes a very efficient use of the resources when looking for the Red X, which is what the deviation that causes 80% of the problems is called, by using the previously mentioned statistical approach.

The team had already identified what the root cause of the problem was, therefore using a tool to identify the main culprit wasn't the one that best suited the needs of the team.

c. **DMAIC Six Sigma** – A process used to improve business or manufacturing processes to reduce the variation.

   An example of this process is reducing the variation in the fuel filler cap manufacturing process to create more consistent fuel filler cap assemblies, which in turn will help tighten the range of force needed to close the cap.

   DMAIC (Define, measure, analyze, improve, and control) is a meta-routine: a routine for changing established routines or for designing new routines (Schroeder et al., 2008). Originally described as a method for variation reduction, DMAIC is applied in practice as a generic problem solving and improvement approach (McAdam and Lafferty, 2004). It is instrumental in the implementation of Six Sigma as a process improvement methodology (Chakravorty, 2009).

   DMAIC would have also been a valid approach to the problem previously defined, however due to the resources and knowledge available at the time, it was decided that the DFSS approach was better.

d. **Lean Six Sigma** – A process used to improve business and manufacturing processes by increasing the speed of the process by eliminating waste. In this case waste does not only refer to waste in material, but also in time, space, and resources in general.

An example of this process is increasing the line speed of the fuel filler cap manufacturing line by eliminating wasteful movements, keeping all the stations where the part goes through closer to each other while eliminating any unnecessary steps in between.

Lean Six Sigma is a business strategy and methodology that increases process performance resulting in enhanced customer satisfaction and improved bottom line results. (Snee, 2010, p10). It is also being widely recognized that Lean Six Sigma is an effective leadership development tool. Welch and Welch (2005) points out that "Perhaps the biggest but most unheralded benefit of Six Sigma is its capacity to develop a cadre of great leaders."

From a project perspective, green belt (GB) and black belt (BB) projects typically return in excess of $50k and $175k per project, respectively, (Harry, 1998).

Since the purpose of the project wasn't to optimize the process and reduce waste, Lean Six Sigma wasn't the best methodology to follow for this project.

From these four methodologies, the Design for Six Sigma approach is the one that makes most sense since the objective is to meet the customer expectations that the system will be inaudible while driving. The DFSS approach focuses on making the system more robust against the variations that are inherit to the system itself.

As Douglas P. Mader mentions in his publication Design for Six Sigma "Many organizations believe design for Six Sigma (DFSS) is a design process when really it is not. DFSS is an enhancement to an existing new product development (NPD) process that provides more structure and a better way to manage the deliverables, resources, and trade-offs". (Mader, 2002, p82), and that is exactly what the team needed.

Chapter 4: Proposed solution and implementation

To identify what was the most robust solution to the noise issue that the development team was having, it was decided to use the Design for Six Sigma Methodology which consists of five phases, which are Plan, Requirements, Concept, Optimization and finally Verification.

Plan Phase:

The objective of this phase is to confirm that the team is working towards something that is worth working on from THE COMPANY perspective and that the customer will also benefit from the results. This is done by answering the following questions:

- Why are we starting the project?

- What will the project accomplish?
- How will the team approach the opportunity?

The answer must be a clear improvement in performance of a specific business need.

For this particular project, this was the information presented:

1. Why is the team starting the project?

The driver can detect a noise during the EVAP purge cycle during normal driving conditions. From a development perspective, the noise is detected late during the development cycle, which can drive additional costs and cause delays. THE COMPANY currently uses different countermeasures without a clear direction of which ones perform better or where they should be installed to achieve better performance.

2. What will the project accomplish?

The project will determine which countermeasures of the currently used performs better and under which conditions and also will define the Engineering Design Practices for future programs.

3. How will the team approach the opportunity?

Since the project will focus on taking solutions that already exist to avoid additional development and validation costs, we will tackle this problem with only the Plan, Optimization and Verification phases.

Optimization Phase

Moving on to the Optimization phase, the DFSS methodology defines ten different steps to follow, however not all of them were used due to the nature of the project. Here are the steps for a Robust Optimization:

1. Ideal Function
2. Input Strategy
3. Noise Strategy
4. Control Factors
5. Lay Out Experiment
6. Prove Experimental Strategy
7. Complete Experiment
8. Analyze Experiment
9. Create Predictive Model
10. Confirm Model

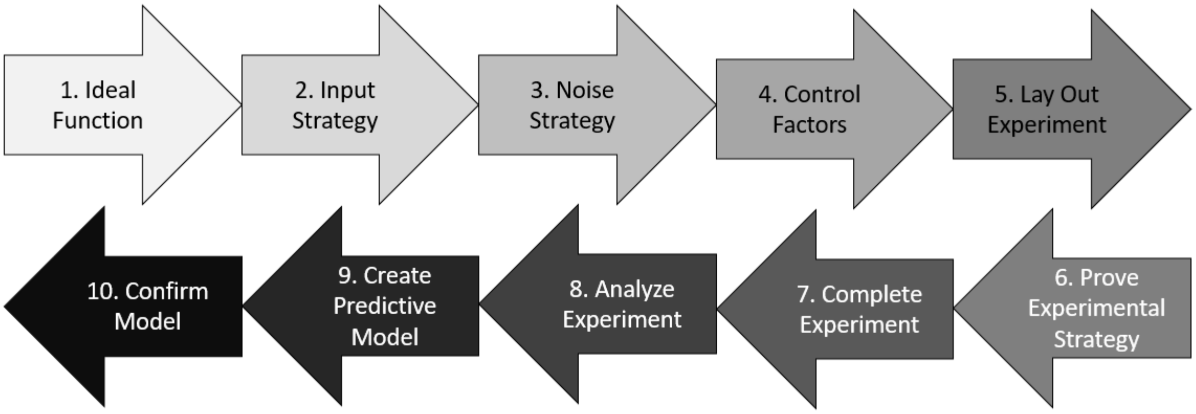


Figure 5 - Robust Optimization Flow. Self-made

For this project, the team decided not to perform a Robust Optimization but instead chose a Robust Comparison, and the steps change as shown in the diagram below.

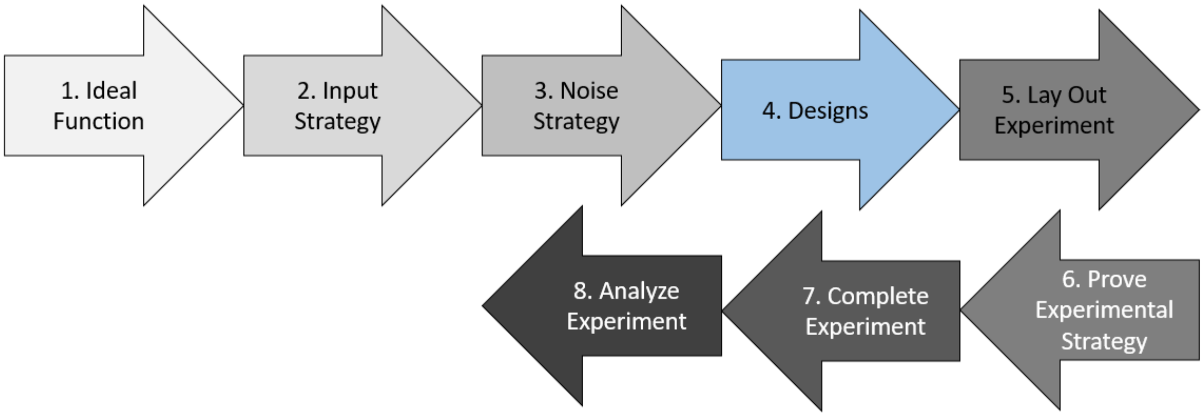


Figure 6 - Robust Comparison Flow. Self-made

The main differences lie in that the Robust Optimization tries to understand and quantify how much each noise and factor contributes to the overall robustness of the solution, while the Robust Comparison takes Designs already stablished instead of Control Factors, and the Create Predictive Model and the Confirm Model steps are skipped. This way the team can obtain the best performing solution under the stablished conditions from a previously selected alternatives, which in this case were parts already manufactured.

The reason behind skipping those steps is that the Robust Comparison, not being a predictive model, usually required to run all the iterations to understand how they contribute to the overall performance, so the Predictive Model and the Confirmation are not necessary.

1. Ideal Function

First, the team must define an Ideal Function of the system that directly correlates with the problem. The ideal function is the way the team expects the intended function to behave in the ideal world.

Through a few iterations and working with team members that had previous experience dealing with similar situations, it was decided that the function was going to be Dampening the purge system pulses. See Figure 7 - System Definition. Self-made

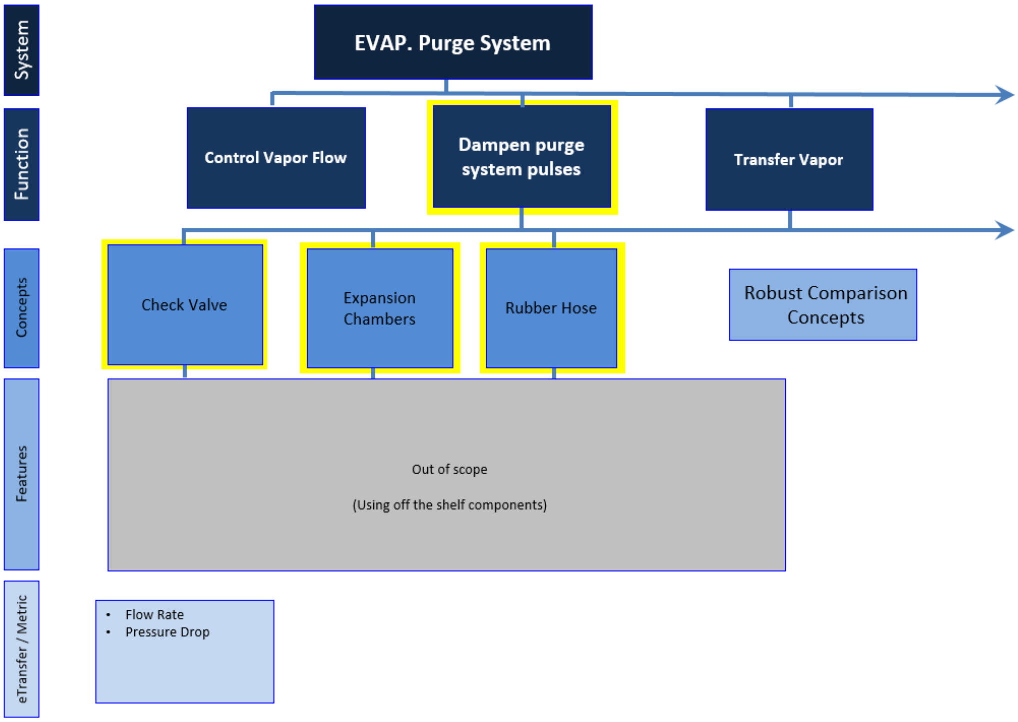


Figure 7 - System Definition. Self-made

2. Input Strategy

After defining the function, the team then defined the Input Strategy. Based on the knowledge of the system, the team knew that the pulsations were caused by the activation of the purge valve, so that became the input: the Duty Cycle Purge (DCP). The DCP is controlled by percentages, and it has been previously identified that the higher the DCP the worst is the condition, however vehicles are limited within a certain threshold, which usually goes from 0% to 30%.

As part of the Input strategy the team must define levels to see how the system behaves at different input values, so it was decided to focus on the range of 20% to 30% as previous experience showed this condition was already severe and on the margin of what a vehicle would experience.

With each input level the number of tests in the following steps of the process increases exponentially, so it was decided to run three levels: 20%, 25% and 30%.

As the DCP is determined by the calibration of the vehicle based on various factors such as fuel tank level, canister loading, which is how much vapor is held in the carbon canister at any given time, temperature and pressure, it was decided to use a PCD drive box which allowed the team to overwrite the calibration and set a specific DCP.

3. Noise Strategy

Then the team defined the Noise Strategy. For this step the team performed a brainstorm of all the different factors that can cause variations in the system and the team doesn't have control over them in general.

In this case, the factors identified where the countermeasure location, the vehicle that was going to be used, which powertrain that vehicle had, the passenger location, the ambient temperature, and the canister loading.

From these factors, the team decided to compound the vehicle and powertrain noises by choosing a single configuration. The canister loading was also removed, as this would only be relevant if the vehicle was purging based on the calibration previously stablished, but as mentioned before during the Input Strategy step, the team had already chosen specific DCP ranges and the PCD drive box was going to be used.

The same way that levels are defined for the input strategy, so it is done for the noise levels given few exceptions. For the countermeasure location, three levels had originally been defined. First was installing the countermeasure close to the purge valve, then close to the canister, and then in the middle of the system, however as the instrumentation and set up of the tests was further developed, it was decided to remove the iterations with the countermeasure in the middle, leaving only two levels. See Figure 8 - Countermeasure Location Relative to the Vehicle. Self-made

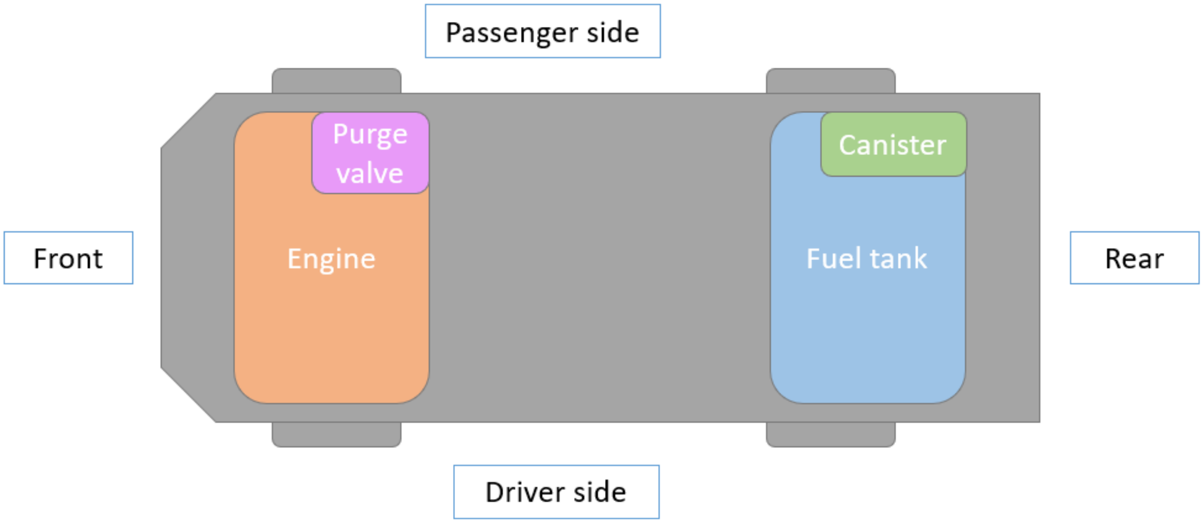


Figure 8 - Countermeasure Location Relative to the Vehicle. Self-made

For the vehicle noise level, two platforms were chosen with a specific powertrain which this document will refer to as Platform 1 and Platform 2. Both platforms had already been identified as being noisy in previous evaluations performed couple years before.

For the passenger location two levels were also chosen. First row and second row. This didn't increase the number of tests that had to be run as the NVH team could just instrument the vehicles at both locations during a single run. This would cut the number of tests required in half. See Figure 9 - Microphones Locations. Self-made

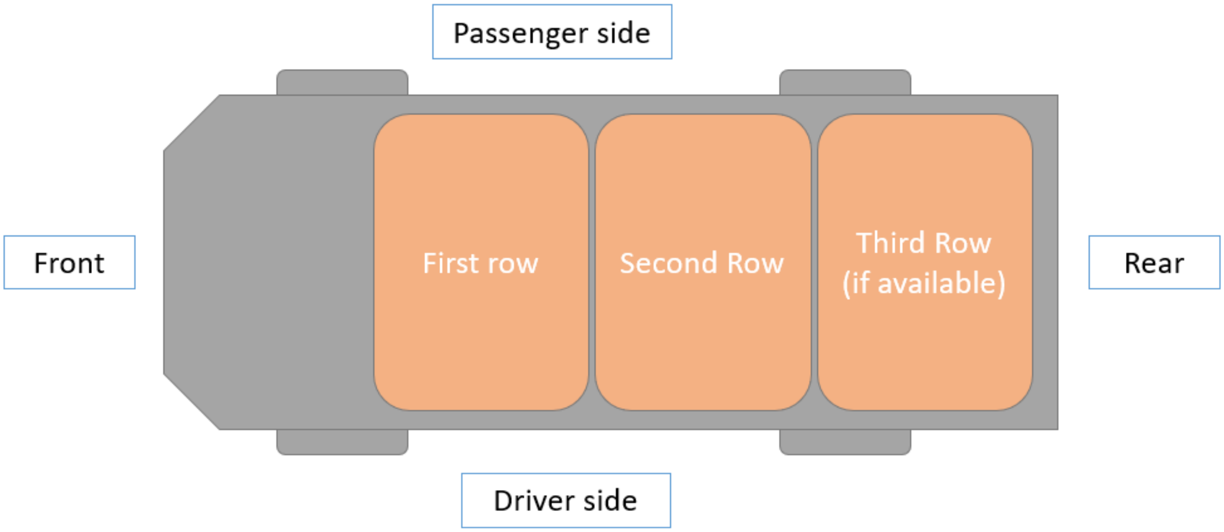
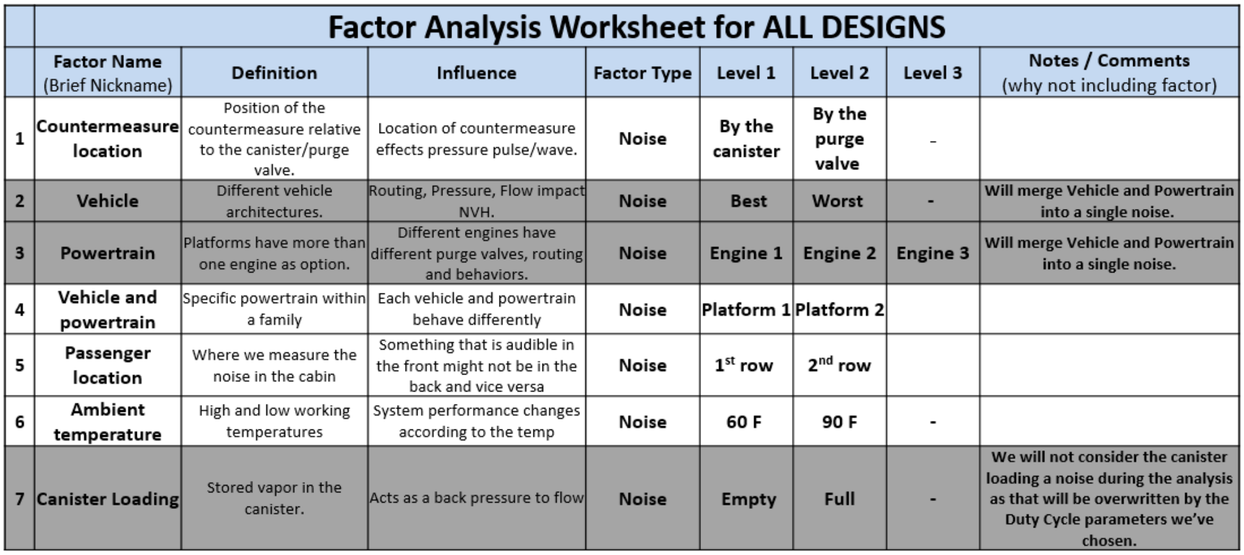


Figure 9 - Microphones Locations. Self-made

Finally, for the ambient temperature, two levels were also chosen. The first one was at 60F and the second one at 90F. The values where the limits that the sound chambers with temperature capability could reach during the summer, as that was the time of the year when the trials were run.

A summary of all the different noise factors along with the control levels is included to allow for a quick visualization of all the data. See Table 1 - Factor Analysis. Self-made



Factor Analysis Worksheet for ALL DESIGNS

	Factor Name (Brief Nickname)	Definition	Influence	Factor Type	Level 1	Level 2	Level 3	Notes / Comments (why not including factor)
1	**Countermeasure location**	Position of the countermeasure relative to the canister/purge valve.	Location of countermeasure effects pressure pulse/wave.	**Noise**	**By the canister**	**By the purge valve**	-	
2	**Vehicle**	Different vehicle architectures.	Routing, Pressure, Flow impact NVH.	**Noise**	**Best**	**Worst**	**-**	**Will merge Vehicle and Powertrain into a single noise.**
3	**Powertrain**	Platforms have more than one engine as option.	Different engines have different purge valves, routing and behaviors.	**Noise**	**Engine 1**	**Engine 2**	**Engine 3**	**Will merge Vehicle and Powertrain into a single noise.**
4	**Vehicle and powertrain**	Specific powertrain within a family	Each vehicle and powertrain behave differently	**Noise**	**Platform 1**	**Platform 2**		
5	**Passenger location**	Where we measure the noise in the cabin	Something that is audible in the front might not be in the back and vice versa	**Noise**	**1st row**	**2nd row**		
6	**Ambient temperature**	High and low working temperatures	System performance changes according to the temp	**Noise**	**60 F**	**90 F**	**-**	
7	**Canister Loading**	Stored vapor in the canister.	Acts as a back pressure to flow	**Noise**	**Empty**	**Full**	**-**	**We will not consider the canister loading a noise during the analysis as that will be overwritten by the Duty Cycle parameters we've chosen.**

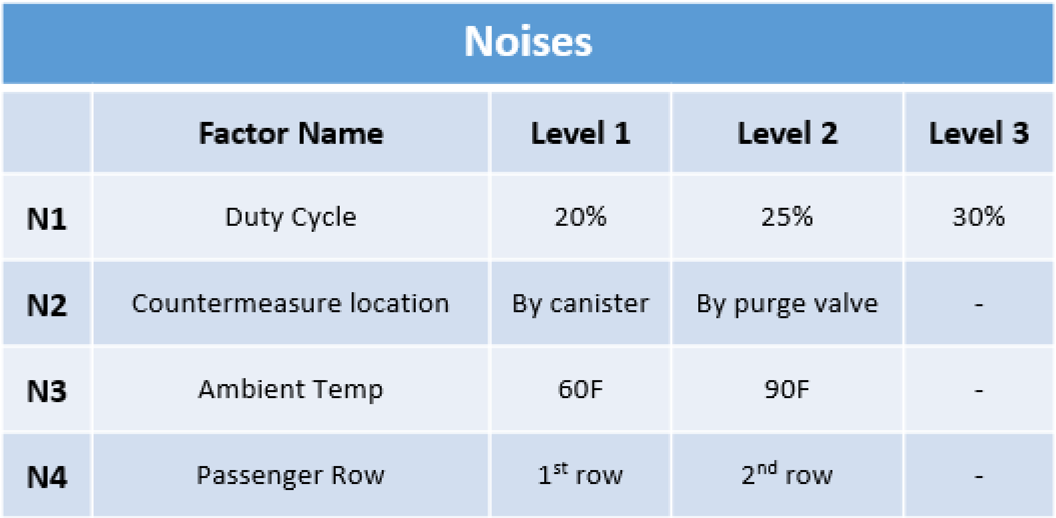
Table 1 - Factor Analysis. Self-made

After defining all the different noises and levels that the team was going to be working with, then the team had to choose the noise strategy to go along with them. There are several strategies on how to apply noise to the experiment, and the most common ones are:

- Predominate: uses a single noise that has a dominant effect on the output.
- Compound: Groups more than one noise into two outputs: Lower Output – when less of the energy is going to the intended output; and Higher output – when more of the energy is going to the intended output.
- Full Factorial: Applies all the combinations of the defined noise factors and levels to the experiment.
- Orthogonal Array: A type of Design of Experiment (DoE) that are used to set up a multifactor experiment with each element showing an equal number of times across the matrix.

The team steered away from any Compounded strategy because the effect of the noises was unknow. This is a critical point because knowledge of the directionality of each noise is needed to make sure they are compounded correctly.

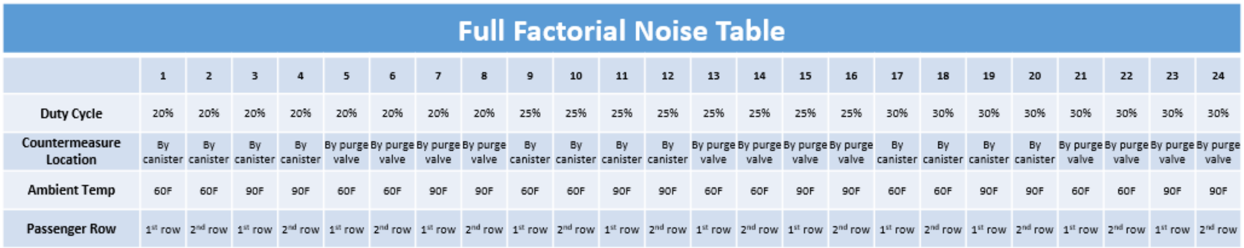
After discarding both the Predominate and the Compound strategy, the team decided to do a Full Factorial because the number of tests required and the sampling time was something manageable, and this would give a higher confidence at the time of analyzing the data collected. See Table 2 - Noise Levels. Self-made and Table 3 - Full Factorial of Noises. Self-made for a summary of the Noises previously identified with their respective levels and the Full Factorial created from matching all the noises levels with each other.



Noises

	Factor Name	Level 1	Level 2	Level 3
N1	Duty Cycle	20%	25%	30%
N2	Countermeasure location	By canister	By purge valve	-
N3	Ambient Temp	60F	90F	-
N4	Passenger Row	1st row	2nd row	-

Table 2 - Noise Levels. Self-made



Full Factorial Noise Table

	1	2	3	4	5	6	7	8	9	10	11	12
Duty Cycle	20%	20%	20%	20%	20%	20%	20%	20%	25%	25%	25%	25%
Countermeasure Location	By canister	By canister	By canister	By canister	By purge valve	By purge valve	By purge valve	By purge valve	By canister	By canister	By canister	By canister
Ambient Temp	60F	60F	90F	90F	60F	60F	90F	90F	60F	60F	90F	90F
Passenger Row	1st row	2nd row	1st row	2nd row	1st row	2nd row	1st row	2nd row	1st row	2nd row	1st row	2nd row

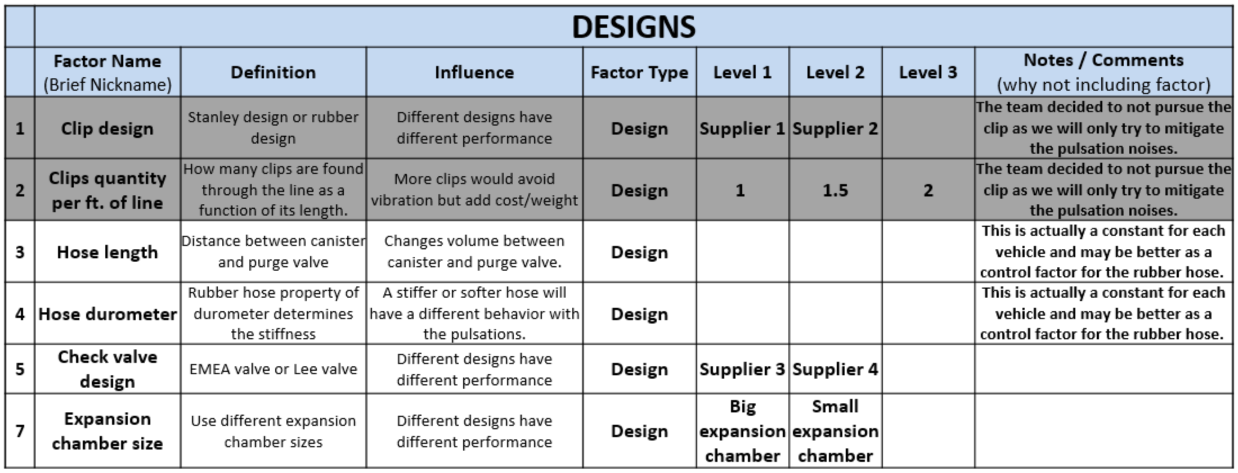
	13	14	15	16	17	18	19	20	21	22	23	24
Duty Cycle	25%	25%	25%	25%	30%	30%	30%	30%	30%	30%	30%	30%
Countermeasure Location	By purge valve	By purge valve	By purge valve	By purge valve	By canister	By canister	By canister	By canister	By purge valve	By purge valve	By purge valve	By purge valve
Ambient Temp	60F	60F	90F	90F	60F	60F	90F	90F	60F	60F	90F	90F
Passenger Row	1st row	2nd row	1st row	2nd row	1st row	2nd row	1st row	2nd row	1st row	2nd row	1st row	2nd row

Table 3 - Full Factorial of Noises. Self-made

4. Control Factors

After stablishing the Noise strategy, the next step is defining the Control Factors. They are the design or process parameters that can be used to stablish the functional performance of a system, sub-system or component during the development of the product, or in other words, these are the design parameters used to improve the current solution.

In this project, which is called a Robust Comparison, the team took designs that already exist and compare one against the others as the name suggests. Instead of having Control Factors the team used already stablished Designs. Nonetheless there were still a few options with some variance that the team investigated. See Table 4 - Designs. Self-made



	DESIGNS							
	Factor Name (Brief Nickname)	**Definition**	**Influence**	**Factor Type**	**Level 1**	**Level 2**	**Level 3**	**Notes / Comments** (why not including factor)
1	**Clip design**	Stanley design or rubber design	Different designs have different performance	**Design**	**Supplier 1**	**Supplier 2**		**The team decided to not pursue the clip as we will only try to mitigate the pulsation noises.**
2	**Clips quantity per ft. of line**	How many clips are found through the line as a function of its length.	More clips would avoid vibration but add cost/weight	**Design**	**1**	**1.5**	**2**	**The team decided to not pursue the clip as we will only try to mitigate the pulsation noises.**
3	**Hose length**	Distance between canister and purge valve	Changes volume between canister and purge valve.	**Design**				**This is actually a constant for each vehicle and may be better as a control factor for the rubber hose.**
4	**Hose durometer**	Rubber hose property of durometer determines the stiffness	A stiffer or softer hose will have a different behavior with the pulsations.	**Design**				**This is actually a constant for each vehicle and may be better as a control factor for the rubber hose.**
5	**Check valve design**	EMEA valve or Lee valve	Different designs have different performance	**Design**	**Supplier 3**	**Supplier 4**		
7	**Expansion chamber size**	Use different expansion chamber sizes	Different designs have different performance	**Design**	**Big expansion chamber**	**Small expansion chamber**		

Table 4 - Designs. Self-made

Finally, a total of five different design alternatives were chosen plus one more for the baseline without any sort of countermeasure. See Figure 10 - All Countermeasures. Self-made

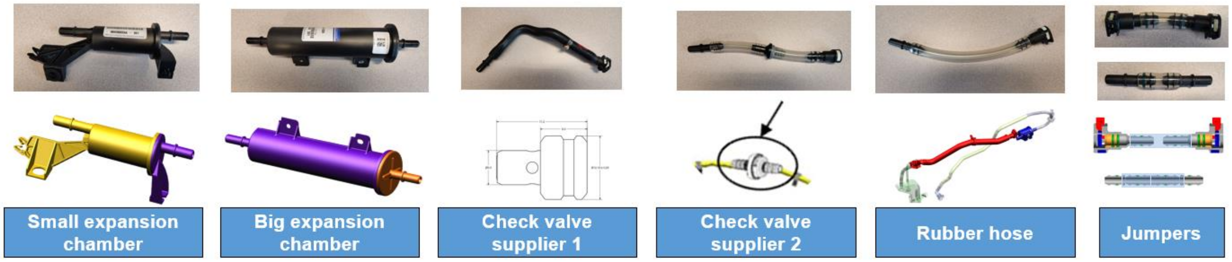


Figure 10 - All Countermeasures. Self-made

Once the team had defined the function, input, noises and designs, then it was time to go back to the ideal function to determine the type of response that was needed.

The team decided that Smaller the Better would be the one that best described the intent of the project. The Smaller the Better function tries to reduce the variation as much as possible as well as bringing the nominal values of the output closer to zero. As the team wanted to get rid of the noise, it made sense that the closer the value of noise perception was to 0 the better it would be. See Figure 11 - Ideal Function. Self-made

Also, after working with the NVH team, it was decided that the Output response for the project was going to be the NVH modulation data. This is a value obtained through a sweep of different frequencies over a noise spectrum and is defined in one of THE COMPANY corporate documents officially published internally.

The smaller the modulation data, the less noise the microphones pick up, which means the customer won't be able to hear the noise.

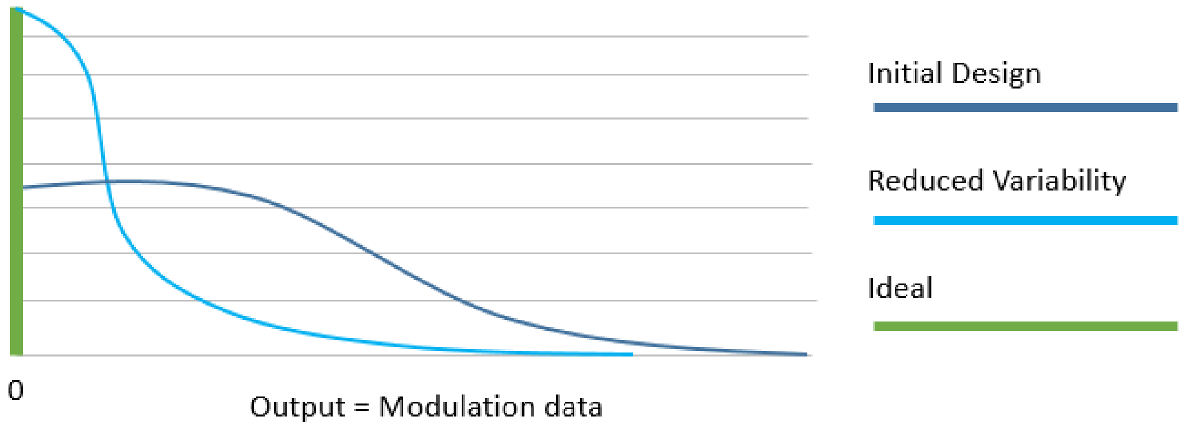


Figure 11 - Ideal Function. Self-made

Here concludes the first series of steps of the Optimization phase.

5. Lay out the Experiment

The fifth step in the Optimization phase is Lay out the Experiment. This means putting together two key elements from the previous steps: The Control factors (in this case the designs) and the Noise factors along with the noise strategy.

A matrix is created with the designs to be tested and then the noise strategy in front of those designs. When we compare this table to the Full Factorial mentioned before, it can be noted that the Rows noise has been removed. This was the case because the lab where the tests were going to take place could perform both at the same time, so the team chose to declutter the chart to avoid confusions, as there would be only one test performed instead of two per the row noise. See Table 5 - Laying Out the Experiment. Self-made

		Temp 60 F						Temp 90 F					
		By the purge valve			By the canister			By the purge valve			By the canister		
	Concepts	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%
1.	No countermeasure												
2.	Big expansion chamber												
3.	Check Valve Supplier 1												
4.	Check Valve Supplier 2												
5.	Small Expansion Chamber												
6.	Rubber Hose												

Table 5 - Laying Out the Experiment. Self-made

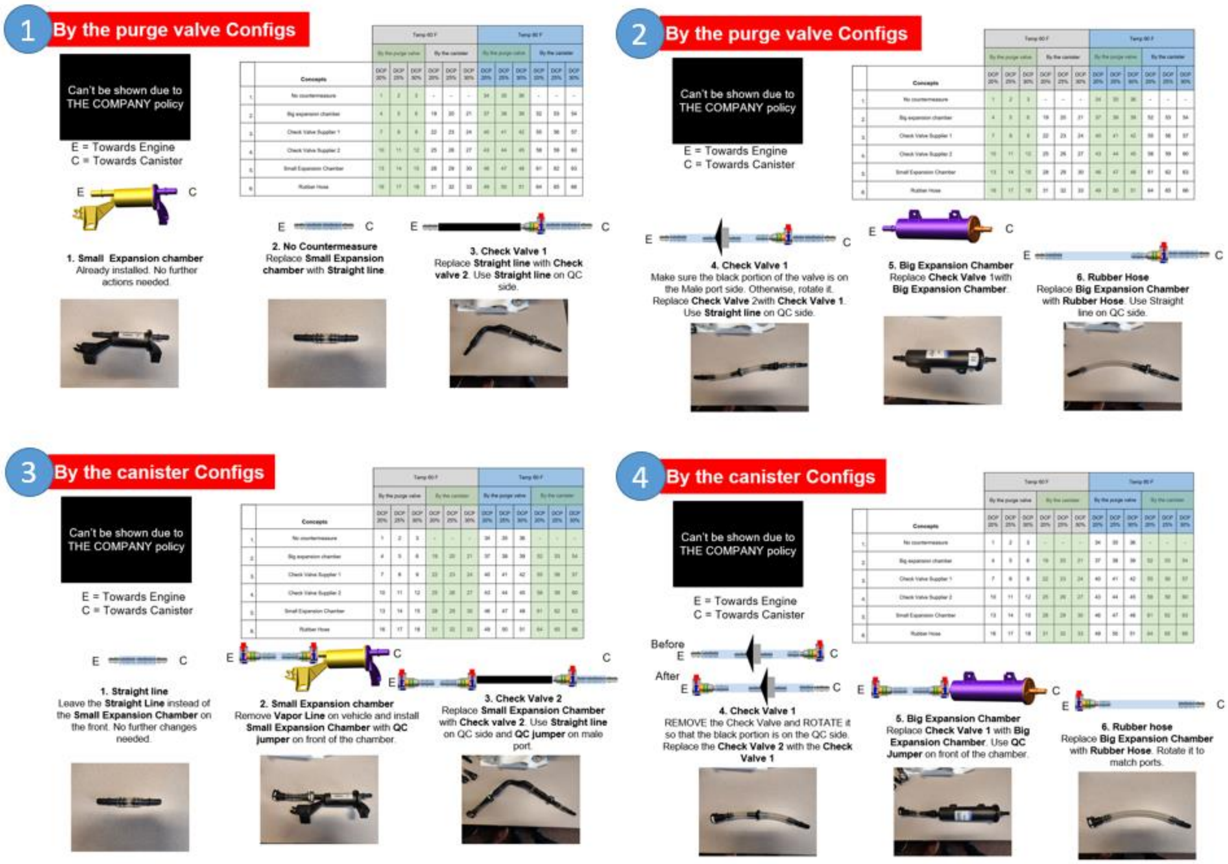
6. Prove Experimental Strategy

Before going through all the iterations, which can consume a lot of time and resources, it is recommended to first run a few trials to make sure everything is going according to plan. If a specific condition is known to be the worst performer, then it is suggested to run that one along one of the better performing to have a good contrast between the two. If the expected worst performer outperforms the best solution, then something is wrong.

Since preparing the vehicle, having it at the required temperature along with the climate chamber, and counting with the assistance of the right team would take a lot of coordination and time, it was decided from the beginning that the NVH lab team was going to run the first trials and if everything went well then, they were going to do the rest of the iterations right away.

The Lab team had to run over 60 trials on the vehicle, so the plan was to have all the parts and configurations readily available and in a manner that wouldn’t take them more than a couple minutes to run each test. For this reason, Platform 1 was chosen. The locations where the countermeasures were going to be introduced were easily accessible without the need of any special tools or a hoist to access the bottom of the vehicle and it would only take couple seconds to swap between one and the other, which meant that a series of test that could take up to weeks if the vehicle had to be moved to a hoist every time something had to be replaced, could be performed in a matter of a few days.

To help the NVH lab performs all the trials correctly, working instructions with diagrams were shared with them to make sure all the correct iterations were run in the most efficient way. See Figure 12 - Experiment Instructions 1. Self-made



1 **By the purge valve Configs**

Can't be shown due to THE COMPANY policy

E = Towards Engine
C = Towards Canister

1. Small Expansion chamber
Already installed. No further actions needed.

2. No Countermeasure
Replace **Small Expansion chamber** with **Straight line**

3. Check Valve 1
Replace **Straight line** with **Check valve 2**. Use **Straight line** on QC side.

2 **By the purge valve Configs**

Can't be shown due to THE COMPANY policy

E = Towards Engine
C = Towards Canister

4. Check Valve 1
Make sure the black portion of the valve is on the Male port side. Otherwise, rotate it. Replace **Check Valve** 2with **Check Valve 1**. Use **Straight line** on QC side.

5. Big Expansion Chamber
Replace **Check Valve** 1with **Big Expansion Chamber**.

6. Rubber Hose
Replace **Big Expansion Chamber** with **Rubber Hose**. Use Straight line on QC side.

3 **By the canister Configs**

Can't be shown due to THE COMPANY policy

E = Towards Engine
C = Towards Canister

1. Straight line
Leave the **Straight Line** instead of the **Small Expansion Chamber** on the front. No further changes needed.

2. Small Expansion chamber
Remove **Vapor Line** on vehicle and install **Small Expansion Chamber** with **QC jumper** on front of the chamber.

3. Check Valve 2
Replace **Small Expansion Chamber** with **Check valve 2**. Use **Straight line** on QC side and **QC jumper** on male port.

4 **By the canister Configs**

Can't be shown due to THE COMPANY policy

E = Towards Engine
C = Towards Canister

4. Check Valve 1
REMOVE the Check Valve and ROTATE it so that the black portion is on the QC side. Replace the **Check Valve 2** with the **Check Valve 1**

5. Big Expansion Chamber
Replace **Check Valve 1** with **Big Expansion Chamber**. Use **QC Jumper** on front of the chamber.

6. Rubber hose
Replace **Big Expansion Chamber** with **Rubber Hose**. Rotate it to match ports.

Figure 12 - Experiment Instructions 1. Self-made

As mentioned before, the team had already identified the Platform 1, which had a history of being noisy, so the two trials to be ran were the Platform 1 with the Small expansion chamber, as that is what it was currently using and what was known to perform well, and also the same Platform 1 without any countermeasure, as this would guarantee a good contrast between the best and the worst performers.

It was during this step that the team realized that the Platform 1 with or without any countermeasure didn't perform very differently one from another. This proved to go against the assumptions from the team: that a vehicle that couple years ago displayed said behavior would still show it at the time.

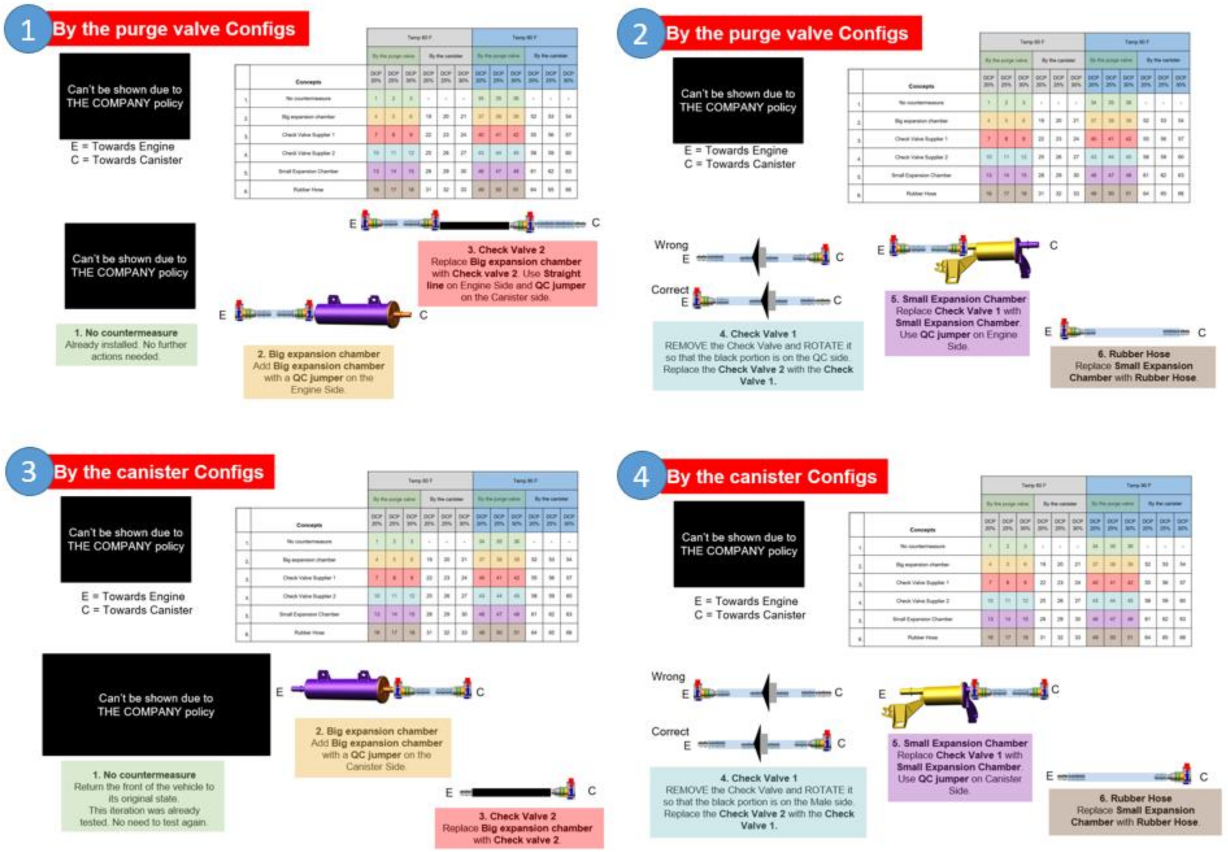
After obtaining a few other vehicles of the Platform 1 the same conclusions were drawn. The latest models of the Platform 1 no longer presented the noise condition. This could be a consequence of calibration changes through the years, as well as design changes in both the

EVAP system and on the rest of the vehicle.

From this point forward the team decided to work with the Platform 2 as there was a study that had been performed couple months before the project that presented evidence that the noise condition was still there.

Working with Platform 2 was more challenging because the location where the countermeasure was located was only accessible through a hoist because it sat by the fuel tank.

To address this concern, the team decided to use a metal line instead of the countermeasure and then a new location was chosen to introduce the different designs. Also new diagrams were made to match the new system, location, and connection points because from vehicle to vehicle that changes. See Figure 13 - Experiment Instructions 2. Self-made



1 By the purge valve Configs

Can't be shown due to THE COMPANY policy

E = Towards Engine
C = Towards Canister

Can't be shown due to THE COMPANY policy

1. No countermeasure
Already installed. No further actions needed.

2. Big expansion chamber
Add **Big expansion chamber** with a **QC jumper** on the Engine Side.

3. Check Valve 2
Replace **Big expansion chamber** with **Check valve 2**. Use **Straight line** on Engine Side and **QC jumper** on the Canister side.

2 By the purge valve Configs

Can't be shown due to THE COMPANY policy

E = Towards Engine
C = Towards Canister

4. Check Valve 1
REMOVE the Check Valve and ROTATE it so that the black portion is on the QC side. Replace the **Check Valve 2** with the **Check Valve 1.**

5. Small Expansion Chamber
Replace **Check Valve 1** with **Small Expansion Chamber**. Use **QC jumper** on Engine Side.

6. Rubber Hose
Replace **Small Expansion Chamber** with **Rubber Hose**.

3 By the canister Configs

Can't be shown due to THE COMPANY policy

E = Towards Engine
C = Towards Canister

Can't be shown due to THE COMPANY policy

1. No countermeasure
Return the front of the vehicle to its original state.
This iteration was already tested. No need to test again.

2. Big expansion chamber
Add **Big expansion chamber** with a **QC jumper** on the Canister Side.

3. Check Valve 2
Replace **Big expansion chamber** with **Check valve 2**.

4 By the canister Configs

Can't be shown due to THE COMPANY policy

E = Towards Engine
C = Towards Canister

4. Check Valve 1
REMOVE the Check Valve and ROTATE it so that the black portion is on the Male side. Replace the **Check Valve 2** with the **Check Valve 1.**

5. Small Expansion Chamber
Replace **Check Valve 1** with **Small Expansion Chamber**. Use **QC jumper** on Canister Side.

6. Rubber Hose
Replace **Small Expansion Chamber** with **Rubber Hose**.

Figure 13 - Experiment Instructions 2. Self-made

After all the required preparations, the NVH team performed the evaluation on the first configurations, the one without any countermeasure and then with the Big expansion chamber. As expected, the no countermeasure solution performed worse than with the countermeasure, so the team moved forward with the rest of the iterations.

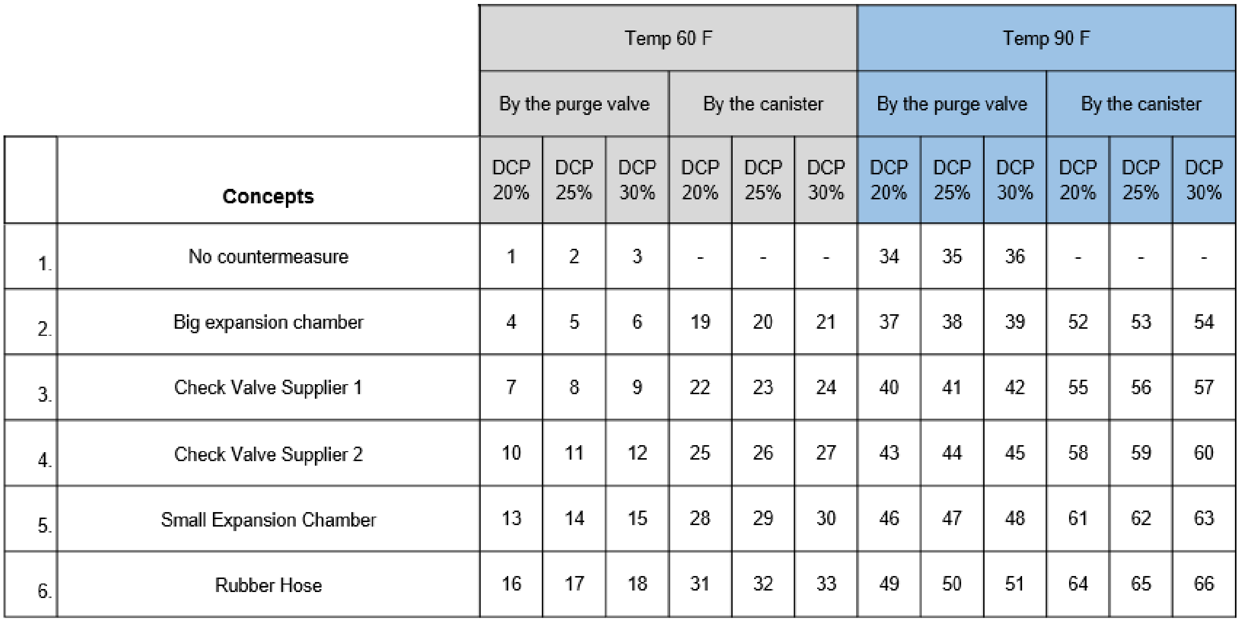
7. Complete Experiment

The Complete Experiment step focuses on running the rest of the iterations after having confidence through the Prove Experiment Strategy step that things will go as expected.

Since 1-6 had already been run, the team performed the evaluation of 7-66 through the series of a few days since the temperature chamber had to be adjusted and let the vehicle soak there for some time to make sure everything was at the same temperature. See Table 6 - Complete Experiment. Self-made

It is worth mentioning that for the No countermeasure row there are only six instead of twelve tests. This is because not having a countermeasure applies to both the purge valve side and the canister side simultaneously, therefore the results is exactly the same for both tests.

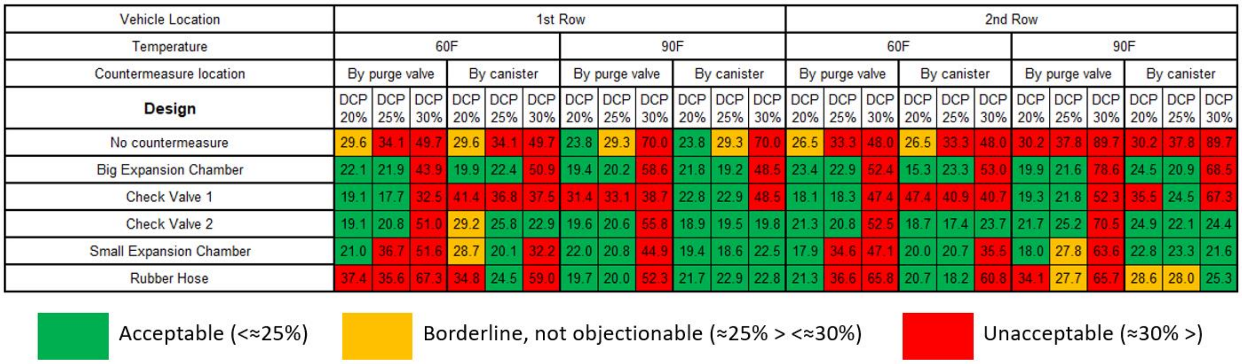
Also as mentioned previously, the NVH team will have twice as many data points because of the Passenger row level which is not in the table.



		Temp 60 F						Temp 90 F					
		By the purge valve			By the canister			By the purge valve			By the canister		
	Concepts	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%
1.	No countermeasure	1	2	3	-	-	-	34	35	36	-	-	-
2.	Big expansion chamber	4	5	6	19	20	21	37	38	39	52	53	54
3.	Check Valve Supplier 1	7	8	9	22	23	24	40	41	42	55	56	57
4.	Check Valve Supplier 2	10	11	12	25	26	27	43	44	45	58	59	60
5.	Small Expansion Chamber	13	14	15	28	29	30	46	47	48	61	62	63
6.	Rubber Hose	16	17	18	31	32	33	49	50	51	64	65	66

Table 6 - Complete Experiment. Self-made

The NVH team performed all the tests and presented the results in the form of a chart. See Table 7 - Results. Self-made



Vehicle Location	1st Row												2nd Row											
Temperature	60F						90F						60F						90F					
Countermeasure location	By purge valve			By canister			By purge valve			By canister			By purge valve			By canister			By purge valve			By canister		
Design	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%
No countermeasure	29.6	34.1	49.7	29.6	34.1	49.7	23.8	29.3	70.0	23.8	29.3	70.0	26.5	33.3	48.0	26.5	33.3	48.0	30.2	37.8	89.7	30.2	37.8	89.7
Big Expansion Chamber	22.1	21.9	43.9	19.9	22.4	50.9	19.4	20.2	58.6	21.8	19.2	48.5	23.4	22.9	52.4	15.3	23.3	53.0	19.9	21.6	78.6	24.5	20.9	68.5
Check Valve 1	19.1	17.7	32.5	41.4	36.8	37.5	31.4	33.1	38.7	22.8	22.9	48.5	18.1	18.3	47.4	47.4	40.9	40.7	19.3	21.8	52.3	35.5	24.5	67.3
Check Valve 2	19.1	20.8	51.0	29.2	25.8	22.9	19.6	20.6	55.8	18.9	19.5	19.8	21.3	20.8	52.5	18.7	17.4	23.7	21.7	25.2	70.5	24.9	22.1	24.4
Small Expansion Chamber	21.0	36.7	51.6	28.7	20.1	32.2	22.0	20.8	44.9	19.4	18.6	22.5	17.9	34.6	47.1	20.0	20.7	35.5	18.0	27.8	63.6	22.8	23.3	21.6
Rubber Hose	37.4	35.6	67.3	34.8	24.5	59.0	19.7	20.0	52.3	21.7	22.9	22.8	21.3	36.6	65.8	20.7	18.2	60.8	34.1	27.7	65.7	28.6	28.0	25.3

🟩 Acceptable (<≈25%) 🟨 Borderline, not objectionable (≈25% > <≈30%) 🟥 Unacceptable (≈30% >)

Table 7 - Results. Self-made

Within the table there are two different types of data. One is the Modulation Data that the NVH team obtained through the microphones and is depicted as a percentage within the boxes. The second one is qualitative, since it is the perception of the NVH lab technician while he was taking the measurements and he classified them into three different categories.

The first one, which are the ones highlighted in green, are Acceptable. This meant the technician couldn't hear any noise.

The next one is yellow, which he classified as Borderline. To get clarification of what this meant, the team reached out to him, and he confirmed that it was something he could hear but barely. The NVH team and their technicians have a trained ear to detect noises that most people can't notice, so the technician confirmed the noise was so low almost no one else other than specialized people could hear.

Finally, the red boxes are Unacceptable. And at this point what the technician could hear would go from low noises to loud ones, but since the criteria is that there most no be any noise, then even if it is barely audible it is still unacceptable.

This approach was also very important because the team needed a way to correlate the Modulation Data to what the customer can hear, since that was the most critical aspect. Thanks to the subjective evaluation, it was possible to determine the ranges of modulation where the customer can hear the noise.

The next step in the methodology is 8. Analyze Experiment, which will be covered in the next chapter.

Chapter 5: Results, Analysis and Implementation

8. Analyze Experiment

After running all the tests and obtaining all the data, the team must then analyze the results. Since during the early steps of the project it was already defined that the approach was a Smaller the Better function, we want to evaluate which of the designs was more robust.

For this the team used the Signal to Noise Ratio (S/N), which is a measurement of robustness and has the following characteristics:

1. It is measured in Decibels (dB).
2. When evaluating the different S/N values within a project, a higher S/N value is always better.
3. It is a project specific index, which means that it is relative. You can’t compare the S/N ratio of one project to that of another project.

For STB the ideal output is non-negative with a target of zero and as small variation as possible.

Defining $\bar{y}$ as the average of the output and σ as the standard deviation, STB tries to achieve $\bar{y} = 0$ and $\sigma = 0$. Since that could only happen under ideal circumstances, the purpose is to get as close as possible to those values. See Formula 1 - Mean. Self-made, Formula 2 - Standard Deviation. Self-made, and Formula 3 - Signal to Noise Ratio for Smaller the Better. Self-made for the method on how to calculate the respective performance index.

Data Points (n): count of the number of data points per run

Mean ($\bar{y}$): average of the output

$$\bar{y} = \frac{(\sum_{i=1}^{n} y_i)}{n} = \frac{(y_1 + y_2 + \ \dots y_{n-1} + y_n)}{n}$$

Formula 1 - Mean. Self-made

Standard deviation (σ): measure of data set spread from the mean

$$\sigma = \sqrt{\frac{\Sigma(y_i - \bar{y})^2}{n-1}} = \sqrt{\frac{(y_1 - \bar{y})^2 + \ (y_2 - \bar{y})^2 \dots (y_{n-1} - \bar{y})^2 + (y_n + \bar{y})^2}{n-1}}$$

Formula 2 - Standard Deviation. Self-made

Signal to Noise Ratio (S/N):

$$\text{S/N}_{\text{STB}} = -10\,\text{Log}(\bar{y}^2 + \sigma^2)$$

Formula 3 - Signal to Noise Ratio for Smaller the Better. Self-made

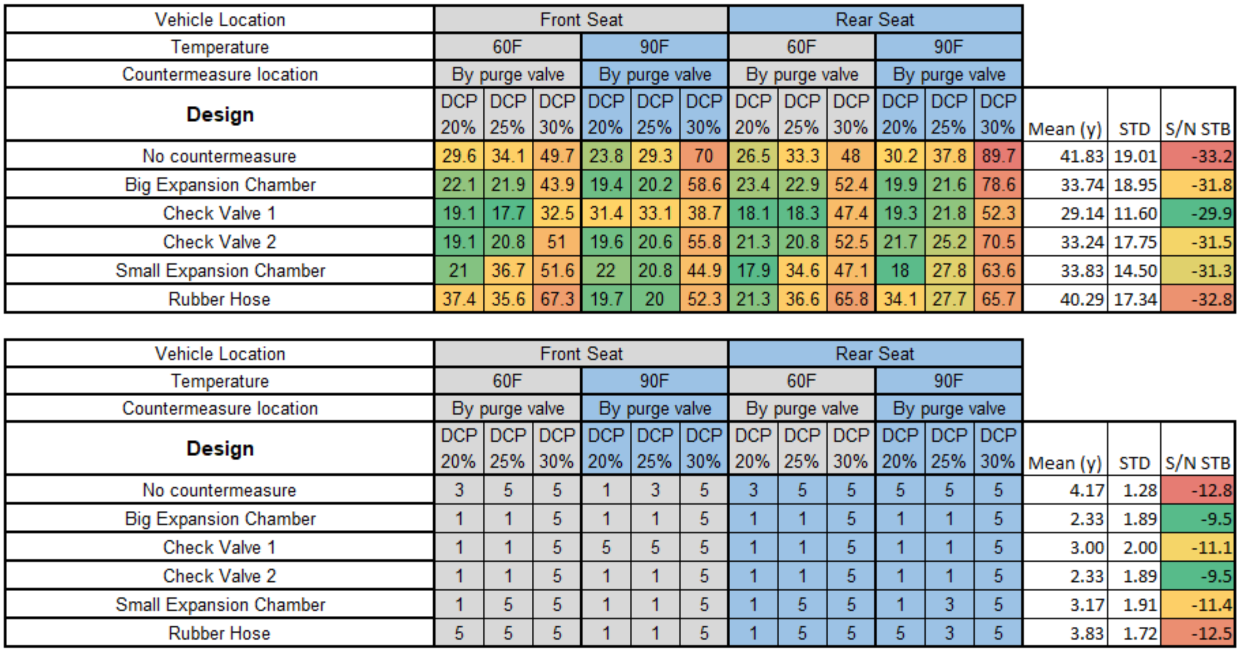
Since the team wanted to quantify the performance of the qualitative data, then the following scale was proposed, and the matrix was filled out to match those values. This wat there were two different sets of quantitative data that the team was then able to evaluate using the S/N values. See Table 8 - Subjective Evaluation. Self-made

Condition	Score
Acceptable	1
Borderline	3
Unacceptable	5

Table 8 - Subjective Evaluation. Self-made

The table was analyzed separately for the values obtained when the countermeasure was installed by the purge valve and those values obtained when the countermeasures were installed by the canister.

In another table, the values obtained by installing the countermeasures by the purge valve are presented. See Table 9 - Signal to Noise Ratio for Purge Valve location. Self-made



Vehicle Location	Front Seat						Rear Seat								
Temperature	60F			90F			60F			90F					
Countermeasure location	By purge valve			By purge valve			By purge valve			By purge valve					
Design	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	Mean (y)	STD	S/N STB
No countermeasure	29.6	34.1	49.7	23.8	29.3	70	26.5	33.3	48	30.2	37.8	89.7	41.83	19.01	-33.2
Big Expansion Chamber	22.1	21.9	43.9	19.4	20.2	58.6	23.4	22.9	52.4	19.9	21.6	78.6	33.74	18.95	-31.8
Check Valve 1	19.1	17.7	32.5	31.4	33.1	38.7	18.1	18.3	47.4	19.3	21.8	52.3	29.14	11.60	-29.9
Check Valve 2	19.1	20.8	51	19.6	20.6	55.8	21.3	20.8	52.5	21.7	25.2	70.5	33.24	17.75	-31.5
Small Expansion Chamber	21	36.7	51.6	22	20.8	44.9	17.9	34.6	47.1	18	27.8	63.6	33.83	14.50	-31.3
Rubber Hose	37.4	35.6	67.3	19.7	20	52.3	21.3	36.6	65.8	34.1	27.7	65.7	40.29	17.34	-32.8

Vehicle Location	Front Seat						Rear Seat								
Temperature	60F			90F			60F			90F					
Countermeasure location	By purge valve			By purge valve			By purge valve			By purge valve					
Design	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	Mean (y)	STD	S/N STB
No countermeasure	3	5	5	1	3	5	3	5	5	5	5	5	4.17	1.28	-12.8
Big Expansion Chamber	1	1	5	1	1	5	1	1	5	1	1	5	2.33	1.89	-9.5
Check Valve 1	1	1	5	5	5	5	1	1	5	1	1	5	3.00	2.00	-11.1
Check Valve 2	1	1	5	1	1	5	1	1	5	1	1	5	2.33	1.89	-9.5
Small Expansion Chamber	1	5	5	1	1	5	1	5	5	1	3	5	3.17	1.91	-11.4
Rubber Hose	5	5	5	1	1	5	1	5	5	5	3	5	3.83	1.72	-12.5

Table 9 - Signal to Noise Ratio for Purge Valve location. Self-made

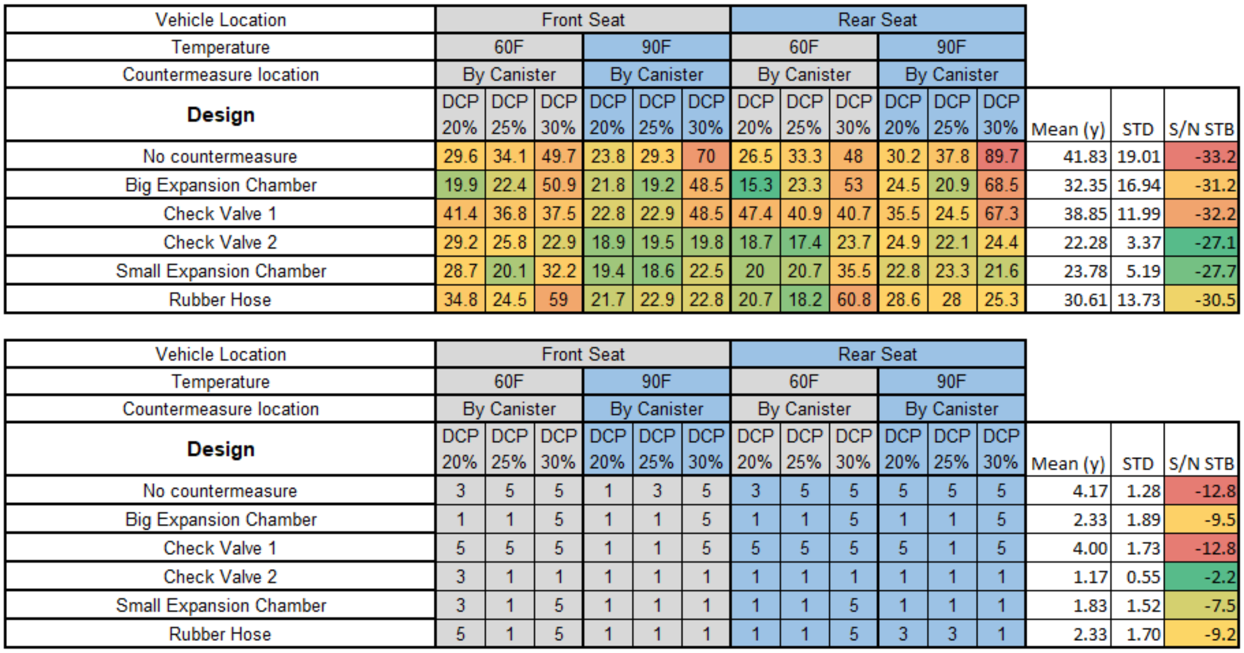
It is worthwhile to note that the S/N values of both tables are very different because one refers to the Modulation data and the other one to the subjective evaluation and the rating that the team gave it.

As mentioned before when stablishing the properties of the S/N, it was explained that a larger S/N is better. Based on this, when looking at the Modulation data the best performer is the Check Valve 1, and the worst performer is the system without any countermeasure, which made a lot of sense considering the worst condition tested was the system without countermeasures.

When looking at the subjective data from the Lab technician it is noticeable that the best performers are the Big expansion chamber and also the Check Valve 2.

The results that the team obtained in this scenario are different from the previous table, and the reason is that the subjective scale doesn’t care for the magnitude of the noise, just that it is present. Both the Big expansion chamber and the Check Valve 2 only present the noise concern at the highest DCP range, but when the noise is present, it is significantly louder than in the cause of the Check Valve 1 that overall has a lower noise threshold, even though it is audible more often.

In the next table are presented the values obtained by installing the countermeasures by the canister. See Table 10 - Signal to Noise Ratio for Canister location. Self-made



Vehicle Location	Front Seat						Rear Seat								
Temperature	60F			90F			60F			90F					
Countermeasure location	By Canister			By Canister			By Canister			By Canister					
Design	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	Mean (y)	STD	S/N STB
No countermeasure	29.6	34.1	49.7	23.8	29.3	70	26.5	33.3	48	30.2	37.8	89.7	41.83	19.01	-33.2
Big Expansion Chamber	19.9	22.4	50.9	21.8	19.2	48.5	15.3	23.3	53	24.5	20.9	68.5	32.35	16.94	-31.2
Check Valve 1	41.4	36.8	37.5	22.8	22.9	48.5	47.4	40.9	40.7	35.5	24.5	67.3	38.85	11.99	-32.2
Check Valve 2	29.2	25.8	22.9	18.9	19.5	19.8	18.7	17.4	23.7	24.9	22.1	24.4	22.28	3.37	-27.1
Small Expansion Chamber	28.7	20.1	32.2	19.4	18.6	22.5	20	20.7	35.5	22.8	23.3	21.6	23.78	5.19	-27.7
Rubber Hose	34.8	24.5	59	21.7	22.9	22.8	20.7	18.2	60.8	28.6	28	25.3	30.61	13.73	-30.5

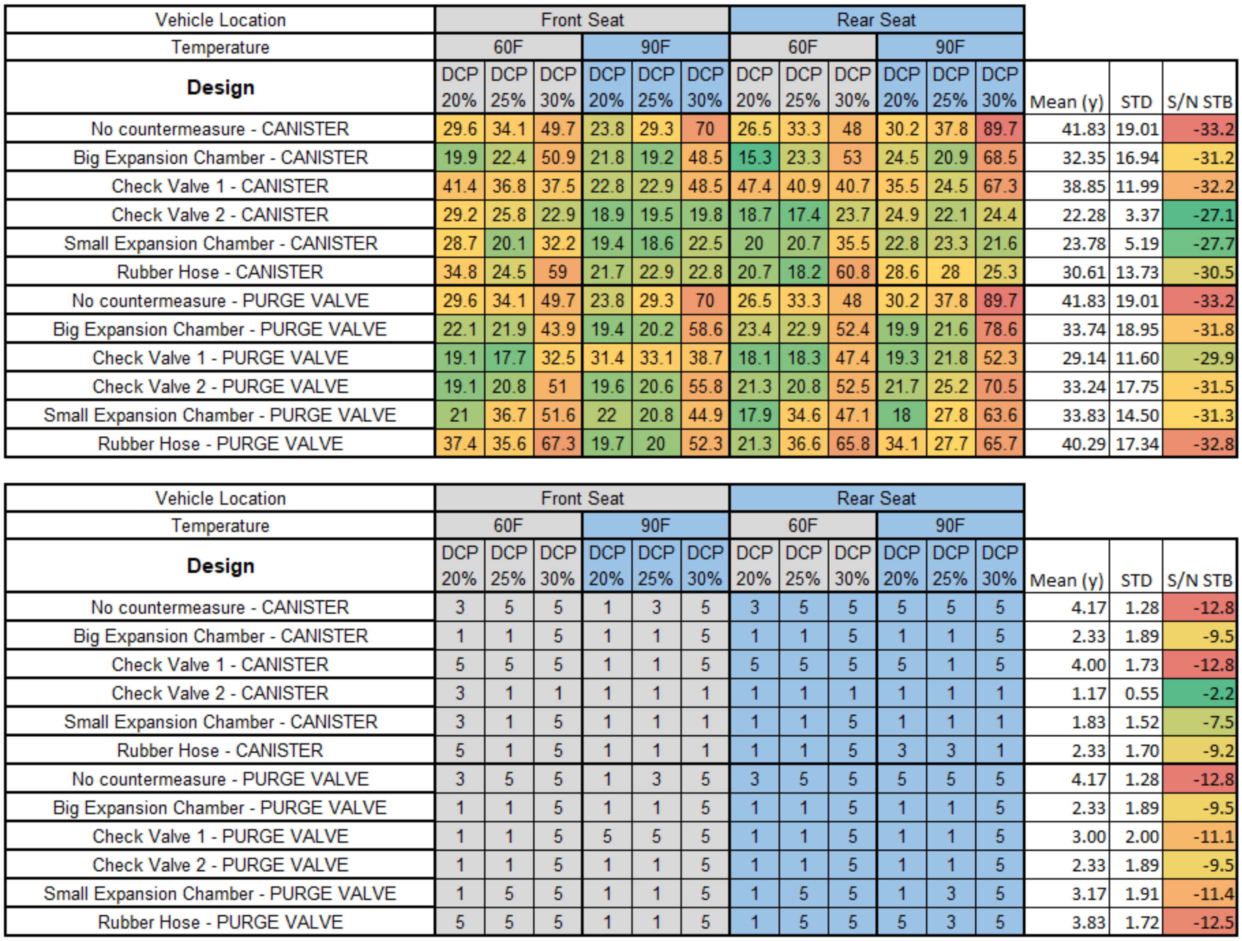
Vehicle Location	Front Seat						Rear Seat								
Temperature	60F			90F			60F			90F					
Countermeasure location	By Canister			By Canister			By Canister			By Canister					
Design	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	Mean (y)	STD	S/N STB
No countermeasure	3	5	5	1	3	5	3	5	5	5	5	5	4.17	1.28	-12.8
Big Expansion Chamber	1	1	5	1	1	5	1	1	5	1	1	5	2.33	1.89	-9.5
Check Valve 1	5	5	5	1	1	5	5	5	5	5	1	5	4.00	1.73	-12.8
Check Valve 2	3	1	1	1	1	1	1	1	1	1	1	1	1.17	0.55	-2.2
Small Expansion Chamber	3	1	5	1	1	1	1	1	5	1	1	1	1.83	1.52	-7.5
Rubber Hose	5	1	5	1	1	1	1	1	5	3	3	1	2.33	1.70	-9.2

Table 10 - Signal to Noise Ratio for Canister location. Self-made

From the evaluation of the values obtained with the countermeasures installed by the canisters, it was observed that, according to the Modulation data, the best performer was the Check Valve 2 followed by the Small Expansion Chamber.

In this case, when looking at the subjective data the results do match, since the best performer is also the Check Valve 2 followed by the Small expansion chamber. Again, the worst performer was the system without any countermeasure as expected.

Since the team can decide where to implement the countermeasure if required early during the development cycle of a new platform, then the team was not only interested in the best local performers, but the best performer overall.



Vehicle Location	Front Seat						Rear Seat								
Temperature	60F			90F			60F			90F					
Design	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	Mean (y)	STD	S/N STB
No countermeasure - CANISTER	29.6	34.1	49.7	23.8	29.3	70	26.5	33.3	48	30.2	37.8	89.7	41.83	19.01	-33.2
Big Expansion Chamber - CANISTER	19.9	22.4	50.9	21.8	19.2	48.5	15.3	23.3	53	24.5	20.9	68.5	32.35	16.94	-31.2
Check Valve 1 - CANISTER	41.4	36.8	37.5	22.8	22.9	48.5	47.4	40.9	40.7	35.5	24.5	67.3	38.85	11.99	-32.2
Check Valve 2 - CANISTER	29.2	25.8	22.9	18.9	19.5	19.8	18.7	17.4	23.7	24.9	22.1	24.4	22.28	3.37	-27.1
Small Expansion Chamber - CANISTER	28.7	20.1	32.2	19.4	18.6	22.5	20	20.7	35.5	22.8	23.3	21.6	23.78	5.19	-27.7
Rubber Hose - CANISTER	34.8	24.5	59	21.7	22.9	22.8	20.7	18.2	60.8	28.6	28	25.3	30.61	13.73	-30.5
No countermeasure - PURGE VALVE	29.6	34.1	49.7	23.8	29.3	70	26.5	33.3	48	30.2	37.8	89.7	41.83	19.01	-33.2
Big Expansion Chamber - PURGE VALVE	22.1	21.9	43.9	19.4	20.2	58.6	23.4	22.9	52.4	19.9	21.6	78.6	33.74	18.95	-31.8
Check Valve 1 - PURGE VALVE	19.1	17.7	32.5	31.4	33.1	38.7	18.1	18.3	47.4	19.3	21.8	52.3	29.14	11.60	-29.9
Check Valve 2 - PURGE VALVE	19.1	20.8	51	19.6	20.6	55.8	21.3	20.8	52.5	21.7	25.2	70.5	33.24	17.75	-31.5
Small Expansion Chamber - PURGE VALVE	21	36.7	51.6	22	20.8	44.9	17.9	34.6	47.1	18	27.8	63.6	33.83	14.50	-31.3
Rubber Hose - PURGE VALVE	37.4	35.6	67.3	19.7	20	52.3	21.3	36.6	65.8	34.1	27.7	65.7	40.29	17.34	-32.8

Vehicle Location	Front Seat						Rear Seat								
Temperature	60F			90F			60F			90F					
Design	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	DCP 20%	DCP 25%	DCP 30%	Mean (y)	STD	S/N STB
No countermeasure - CANISTER	3	5	5	1	3	5	3	5	5	5	5	5	4.17	1.28	-12.8
Big Expansion Chamber - CANISTER	1	1	5	1	1	5	1	1	5	1	1	5	2.33	1.89	-9.5
Check Valve 1 - CANISTER	5	5	5	1	1	5	5	5	5	5	1	5	4.00	1.73	-12.8
Check Valve 2 - CANISTER	3	1	1	1	1	1	1	1	1	1	1	1	1.17	0.55	-2.2
Small Expansion Chamber - CANISTER	3	1	5	1	1	1	1	1	5	1	1	1	1.83	1.52	-7.5
Rubber Hose - CANISTER	5	1	5	1	1	1	1	1	5	3	3	1	2.33	1.70	-9.2
No countermeasure - PURGE VALVE	3	5	5	1	3	5	3	5	5	5	5	5	4.17	1.28	-12.8
Big Expansion Chamber - PURGE VALVE	1	1	5	1	1	5	1	1	5	1	1	5	2.33	1.89	-9.5
Check Valve 1 - PURGE VALVE	1	1	5	5	5	5	1	1	5	1	1	5	3.00	2.00	-11.1
Check Valve 2 - PURGE VALVE	1	1	5	1	1	5	1	1	5	1	1	5	2.33	1.89	-9.5
Small Expansion Chamber - PURGE VALVE	1	5	5	1	1	5	1	5	5	1	3	5	3.17	1.91	-11.4
Rubber Hose - PURGE VALVE	5	5	5	1	1	5	1	5	5	5	3	5	3.83	1.72	-12.5

Table 11 - All Signal to Noise Ratios. Self-made

When putting all the different countermeasures in the different locations it is clear that the best performer overall is the Check valve 2 by the canister when looking at both the Modulation data and the subjective evaluation. The next best performer is the Small expansion chamber also by the canister. See Table 11 - All Signal to Noise Ratios. Self-made

It is also worth mentioning that if there were constraints that wouldn't allow the team to introduce a countermeasure by the canister, then the best alternative is to introduce the Big expansion chamber by the purge valve.

This marks the last step of the of the Optimization for a Robust Comparison. Step 9. Create Predictive Model and Step 10. Confirm Model are not used in this case, only in Robust Optimization.

The next and final phase in the methodology is the Verification Phase which will be covered in the next chapter.

Chapter 6: Conclusions

Verification Phase

The Verification Phase, which is the last one of the methodology, reduces the risk of selecting a concept that does not meet the requirements of the system in all the other aspects that had not been considered and it is for this reason that it is required for Robust Comparison projects and not just for Robust Optimization. It also helps the team verify that the objectives have been met.

During the Verification Phase, which is the last one, the team must answer the following questions:

1. Have the objectives and failure modes from Plan Phase been addressed?

Yes, the team was able to address the noise complain on the vehicles and was also able to identify the best possible solution from the designs chosen. In addition, the team was able to define new practices for

2. Have important requirements been met?

Yes, the team took the current solutions that are available and evaluated which ones performed better and where, knowledge that will be used moving forward.

3. Has there been any negative impact or harm to other systems?

This question is critical when discussing the results of the project. From the results obtained, one of the conclusions was that the Check Valve 2 was the best performer when mounted by the canister. Although this remains true, it is very important to mention that the Check Valve 2 is not fully compatible with the Emissions Regulations from some countries, so there are limitations to where it could be used, while the expansion chambers don’t fall into any restrictions.

In addition to answering the questions, the team was able to draw the following conclusions from the project:

- Quantifying the performance of the different countermeasures in different locations allows for more flexibility, as packaging constraints are something the design development team must always consider. The team has the alternative to use the Small expansion chamber by the canister, and if not possible, then the Big chamber by the purge valve for vehicles that will be sold in certain markets, or the Check Valve 2, ideally by the canister, in vehicles for a different market
- Although the check valve 2 has the best performance, it has some limitations when it

comes vehicles that use Natural Vacuum Leak Detection systems for OBD compliance, therefore the team would look into using the Small expansion chamber in those cases.
- Specifically for the Platform 2, the Small expansion chamber performs better when mounted in the rear, so the team will investigate replacing the Big expansion chamber with the Small one for a weight and cost reduction of the system.
- Originally, the team was going to use Platform 1 but the “no countermeasure” wasn’t audible across various vehicles, so now a cost reduction investigation is moving forward to remove the Small expansion chamber altogether.

Next steps:
- Remove the Small expansion chamber investigation:
    - Small expansion chamber cost: $3.16
    - Small expansion chamber weight: 0.200lb
- Use Small expansion chamber in Platform 2 investigation:
    - Big expansion chamber cost: $3.73
    - Small expansion chamber cost: $3.16

Chapter 7: Suggestions for future works

Institutionalization:

What document will be updated? Engineering Best Practices for fuel lines, protecting for Small expansion at the rear as worst case scenario or Big expansion chamber at the front if packaging constraints don't allow the Small expansion chamber to be used. Ideally use Check valve 1 on those vehicles that don’t use natural vacuum leak detection systems.

Additionally, for future works along the same lines, it would benefit THE COMPANY to work with the Check Valve supplier 1 because it seems that the valve has capability to reduce the pulsation across a wide range as well, but the attenuation must be higher, so it isn’t audible at all.

Another line of investigation is broadening the search field for different expansion chambers with different sizes and configurations, as well as different valves and solutions all together that are on the market even if not necessarily from suppliers that are in the same country. With globalization and an increase presence of global suppliers and technologies, there are surly to be more solutions out there.

To reduce the amount of time the project could take, taking this project as a framework with the methodology would help complete the evaluations in a shorter period of time.

References

- Mader, D. P. (2002). Design for six sigma. Quality progress, 35(7), 82-86.
- Cudney, E.A., & Agustiady, T.K. (2016). Design for Six Sigma: A Practical Approach through Innovation (1st ed.). CRC Press.
- Chowdhury, S. (2002a), Design for Six Sigma, Dearborn Trade, Dearborn, MI.
- Chowdhury, S. (2002b), The Power of Design for Six Sigma, Dearborn Trade, Dearborn, MI.
- Yang, Kai, and Basem S. El-Haik. 2009. Design for Six Sigma: A Roadmap for Product Development. 2nd ed. New York: McGraw-Hill.
- Watson, G. (2005), Design for Six Sigma, GOAL/QPC, Salem, NH.
- Steiner, S. H., Mackay, R. J., & Ramberg, J. S. (2008). An Overview of the Shainin System TM for Quality Improvement. Quality Engineering, 20(6-19), 37-41.
- Trimarjoko, A., Saroso, D., Purba, H., Hasibuan, S., Jaqin, C & Aisyah, S. (2019). Integration of nominal group technique, Shainin system and DMAIC methods to reduce defective products: A case study of tire manufacturing industry in Indonesia.Management Science Letters, 9(13), 2421-2432.
- Shainin, R.D., 2008. How Lean Is Your Six Sigma Program?,Six SigmaForum Magazine, 7(4), pp.42-45.
- Shainin, R.D., 2007. Multi-Vari Charts. In: F. Ruggeri, ed. 2007. Encyclopedia of Statistics in Quality and Reliability.London: Wiley, 1800 p.
- Steiner, S.H., MacKay, R.J., Ramberg, J.S., 2008. An Overview of the Shainin System™ for Quality.Quality Engineering, 20(1), pp.6-19.
- Snee, R. D. (2010). Lean Six Sigma–getting better all the time. International Journal of Lean Six Sigma.
- Welch, J. and Welch, S. (2005), Winning, Harper Business, New York, NY.
- Harry, M.J. (1998), “Six Sigma: a breakthrough strategy for profitability”, Quality Progress, May, pp. 60-4.
- Creveling, C. M., Slutsky, J., & Antis, D., Jr. (2002). Design for Six Sigma in Technology and Product Development (13th ed.). Prentice Hall.
- Internal documentation that cannot be shared per THE COMPANY policy.