CONSTRUCTION AND TESTING OF THE WAVE BREAKING PROTOTYPE – SLOSH NOISE BAFFLE

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This paper has the objective to present the results and behavior of using a slosh noise baffle solution studied in previous works, by testing prototype parts to capture the noise level of wave braking inside a fuel tank in a "natural environment" of a fuel tank. The hypothesis that stayed at the basis of this test is to evaluate the decibel level in the moment a vehicle breaks from different speeds and by using different fuel level inside the fuel tank.

Keywords: baffle, additive manufacturing, testing, data analysis, decibel level

1. Introduction

1.1 Aim of the study

The paper is part of a science project with the purpose of studying the behavior of a new designed slosh noise baffle inside a fuel tank. The aim of the study was to validate the design of the "link baffle" by testing a prototype and comparing results with a test without any baffle inserted in the fuel tank. The baffle solution to reduce slosh noise inside an automotive fuel tank was presented in several previous works [1], [2].

1.2. Originality

The main theme represents the creation of a new baffle design for fuel tanks in automotive industry that can be adapted to already existing fuel tank without modifying the original design of it. The baffle is needed to decrease noise generated by the fuel waves inside the fuel tank, noise that is impacting more and more the client. The phenomenon is mainly known as "slosh noise" and was described in

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previous works [1], [2]. This paper presents the analysis of the Link baffle model in order to verify the validity of the project and impact in slosh noise decrease.

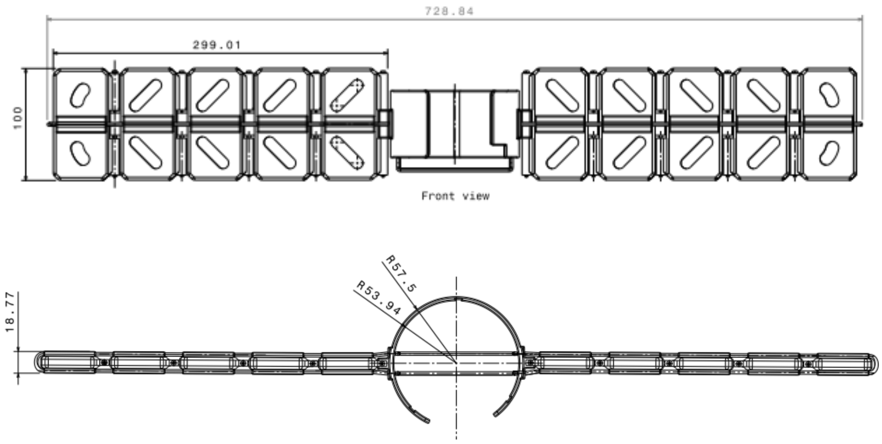


Fig. 1. Link baffle for a standard fuel tank of 55 L volume

2. General consideration for analysis

2.1. Design & manufacturing

This paper has the objectives to test acoustic behavior of a slosh noised baffle solution, based on previous studies, [1], [2]. In fig. 2 is the 3D model of "Link Baffle" solution inserted in a fuel tank. First step of the analysis is to manufacture the components presented in Fig. 2.

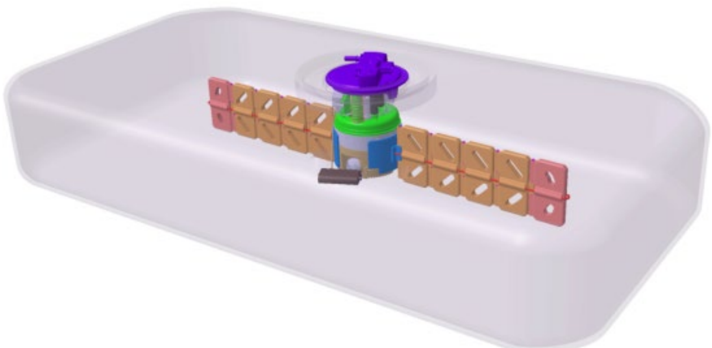


Fig. 2. 3D of Link baffle inside a fuel tank

An important component for this test is represented by the fuel tank. It is used a simple design: a rectangular body with a 55 L volume [1], [2]. To manufacture the prototype fuel tank for testing purposes, there were used 10mm plexiglass plates. The tank is fixed on a support to maintain same position during testing loops.

To simulate the free introduction of a slosh noise baffle, an insertion hole was made in the upper wall of the fuel tank, based on the diameter of pump module superior flange. This will show how an operator will simply insert the baffle in the fuel tank. Another component that was manufactured as a prototype is the fuel pump – module. This will be used for testing in both situations: with and without slosh noise baffle, to better compare the behavior of the fuel inside the tank. To manufacture this, a FDM method was used (Fused Deposition Modelling), (fig.3 – 6).
The paper as the objective to present the results and behavior of using a slosh noise baffle solution in a fuel tank. The Fuel Pump Module is considered only as a generic part in the simulation, only its geometry being the influence in this experimental study present. The geometry of the Generic Fuel delivery part is based on the benchmark studies performed by the authors [1], [2].

Fig. 3. Fuel pump module – lower body

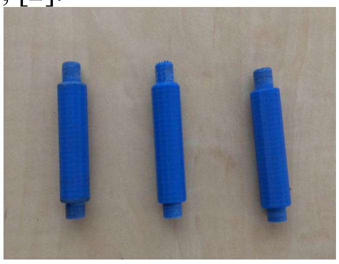


Fig. 4. Fuel pump columns

Fig. 5. Fixation of the column on the module

Fig. 6. Complete fuel pump module

Using the same method as for the fuel pump module, the "Link baffle" solution was manufactured. Every component was 3D printed separately and assembled together using steel pins and cables as per design. All components were printed using a 3D Kreator printer at FIIR Faculty - 3D Printing Laboratory.

2.2. Testing the prototype

Currently, there is no official standard linked to slosh noise phenomena evaluation or method of testing. So, it is up to the developer to create methods to control efficiency of a device designed to reduce slosh noise.

The acoustic test was performed by mounting the prototype fuel tank into a passenger car. The vehicle is a B class automobile, with Start & Stop engine option in order to better record during the testing the decibel level inside the fuel tank at breaking point.
A support is assembled over the tank to fix the decibel measuring unit. This will help to eliminate any other influence factor over the measuring distance, position and stability during recording.
Two types of testing scenarios are put in place:

- the first scenario uses a tank with no baffle included;
- the second scenario use a tank with a wave breaking baffle solution.

For both cases there is registered the decibel level at vehicle breaking point. Decibel level is measured using BOSCH iNVH ver. 1.1. application. The analysis is based also on other parameters displayed in the below table.

Table 1.

Input Data

Simulation Nr.	Baffle type	Liquid volume [l]	Speed before braking [km/h]
S1	No baffle	15	10
S2	No baffle	15	30
S3	No baffle	25	10
S4	No baffle	25	30
S5	No baffle	35	10
S6	No baffle	35	30
S7	No baffle	45	10
S8	No baffle	45	30
Z1	Link Baffle	15	10
Z2	Link Baffle	15	30
Z3	Link Baffle	25	10
Z4	Link Baffle	25	30
Z5	Link Baffle	35	10
Z6	Link Baffle	35	30
Z7	Link Baffle	45	10
Z8	Link Baffle	45	30

The detailed testing method is described in the flow below that will be respected on both sets of tests, the only variables will remain the one in previous table.
Real test conditions as followed:

- Test Bench is located in a closed space that assures distance to accelerate to 30km/h and break to stop – 120m test track situated in a closed warehouse.

- Simulations are executed as flow in figure 7. to keep the variation of data recorded as low as possible.
- Simulations are executed respecting parameters in Table 1.
- Data is recorded by the Bosch iNVH application and saved for each simulation.

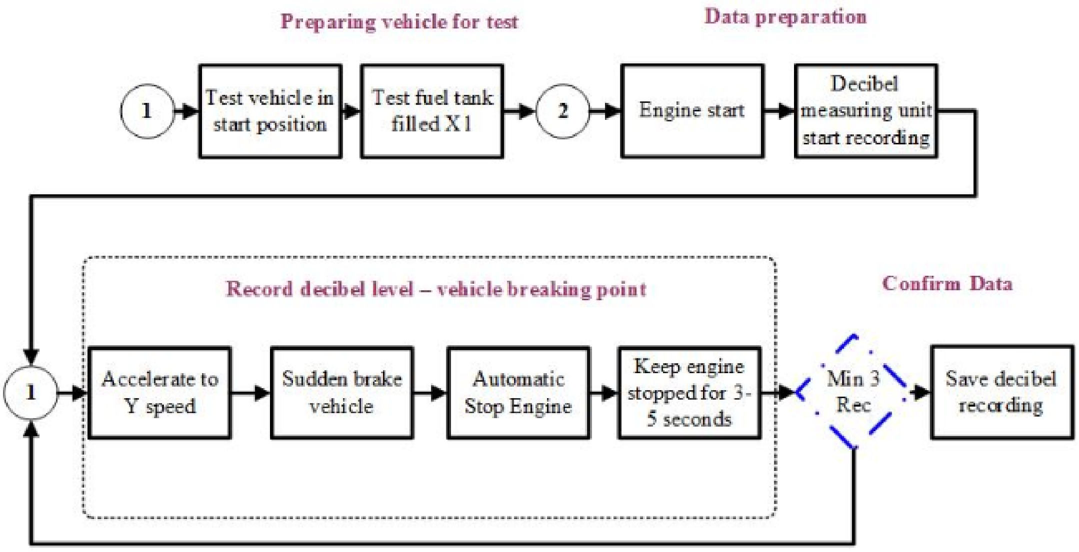
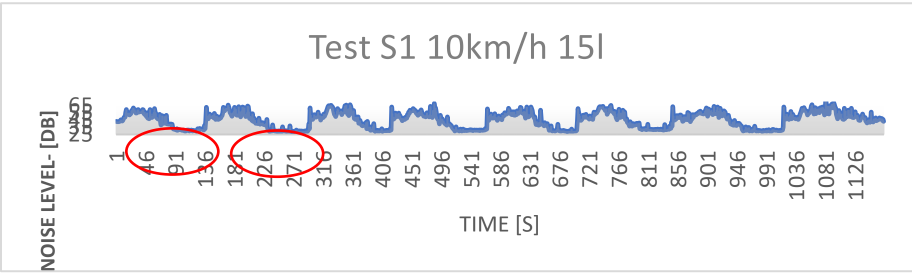


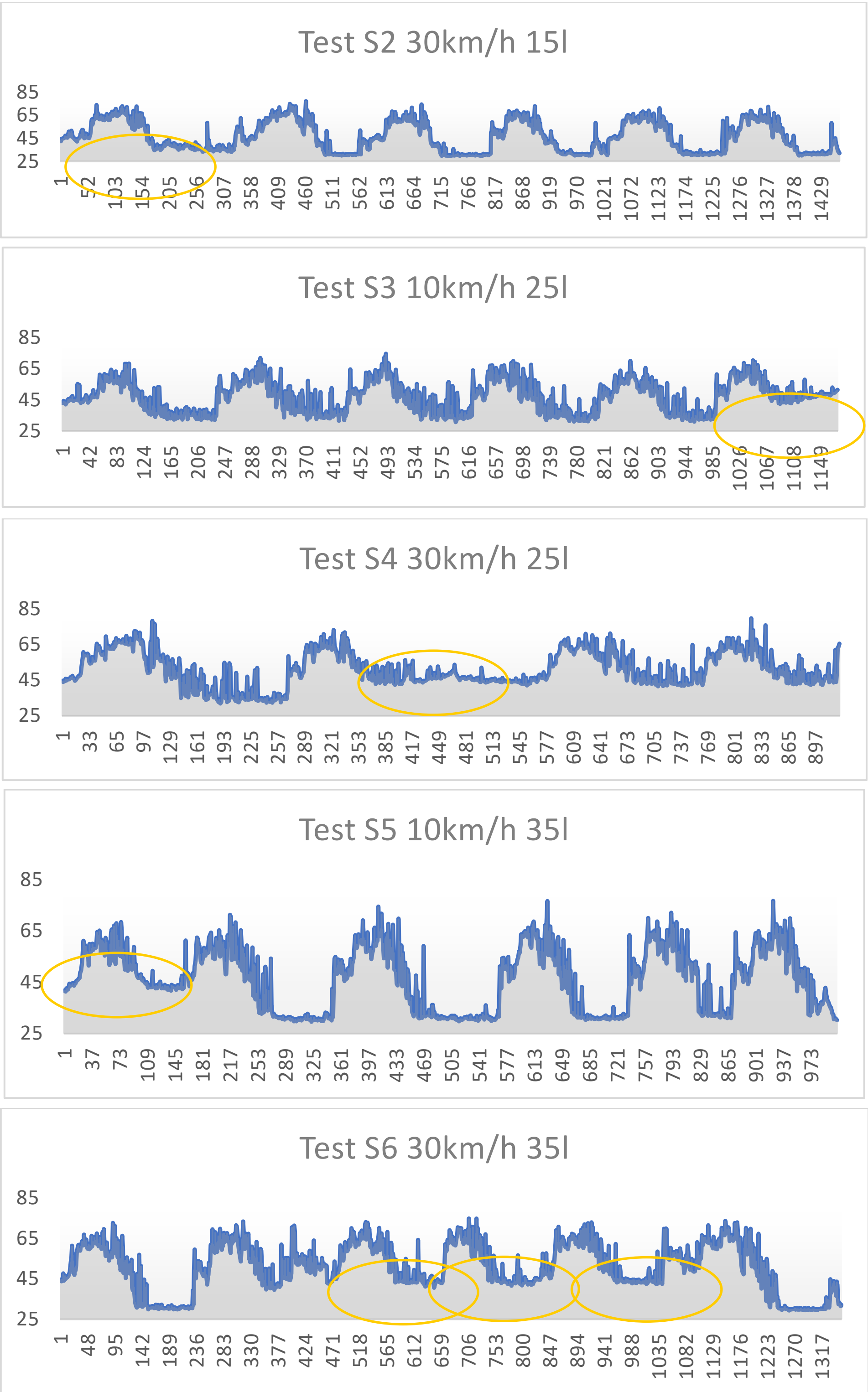
Fig. 7. Test method flow

For the first simulation, the fuel tank in filled in with 15 L of liquid, with pump module inserted and no baffle inside. In the graphic bellow it can be observed the decibel level of the liquid at breaking point after running the car with 10km/h. Inside the red circle was identified the noise produced by the liquid waves inside the fuel tank after engine stop.



Graphic 1: Test S1 10 Km/h 15L

Also, on the other test, variation of the decibel level was recorded after increasing speed of the vehicle and quantity of the liquid.


Test S2 30km/h 15l
85
65
45
25
1 52 103 154 205 256 307 358 409 460 511 562 613 664 715 766 817 868 919 970 1021 1072 1123 1174 1225 1276 1327 1378 1429
Test S3 10km/h 25l
85
65
45
25
1 42 83 124 165 206 247 288 329 370 411 452 493 534 575 616 657 698 739 780 821 862 903 944 985 1026 1067 1108 1149
Test S4 30km/h 25l
85
65
45
25
1 33 65 97 129 161 193 225 257 289 321 353 385 417 449 481 513 545 577 609 641 673 705 737 769 801 833 865 897
Test S5 10km/h 35l
85
65
45
25
1 37 73 109 145 181 217 253 289 325 361 397 433 469 505 541 577 613 649 685 721 757 793 829 865 901 937 973
Test S6 30km/h 35l
85
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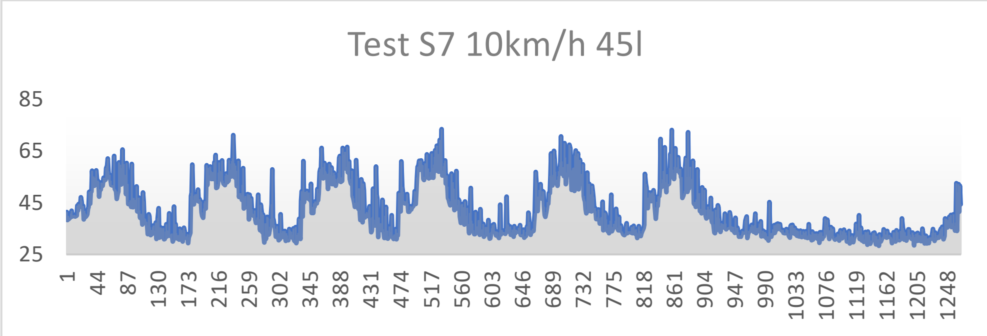
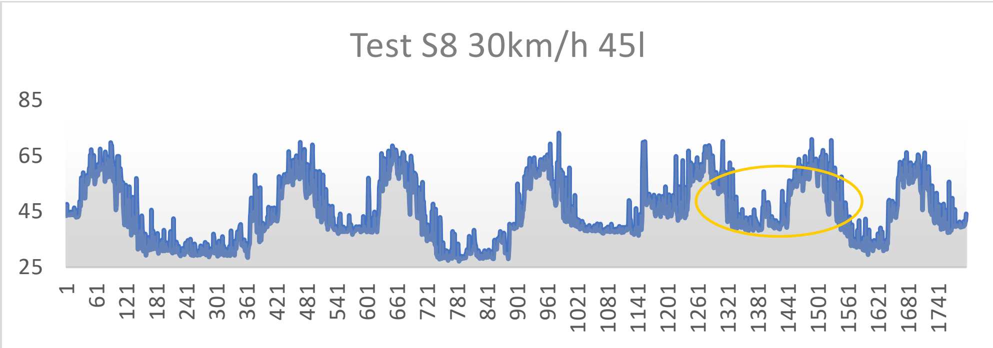
45
25
1 48 95 142 189 236 283 330 377 424 471 518 565 612 659 706 753 800 847 894 941 988 1035 1082 1129 1176 1223 1270 1317



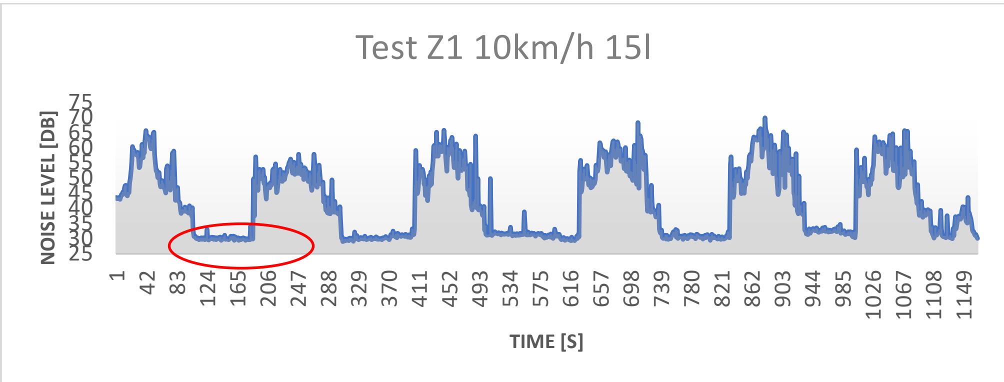


Graphic 2: Decibel level (Y) – no baffle test

Some recordings were influenced by failure of the Start Stop engine, so the data will be identified and separated from the analysis – orange oval in the graphic represent failure and red oval will represent data to be tested.

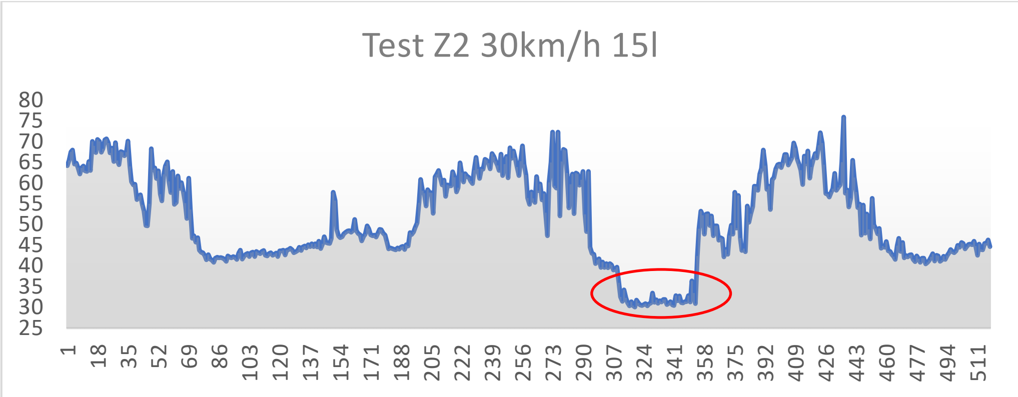
Second simulation set requires introduction of the "Link Baffle" inside the tank. It can be seen in the picture below the simple process of assembly.

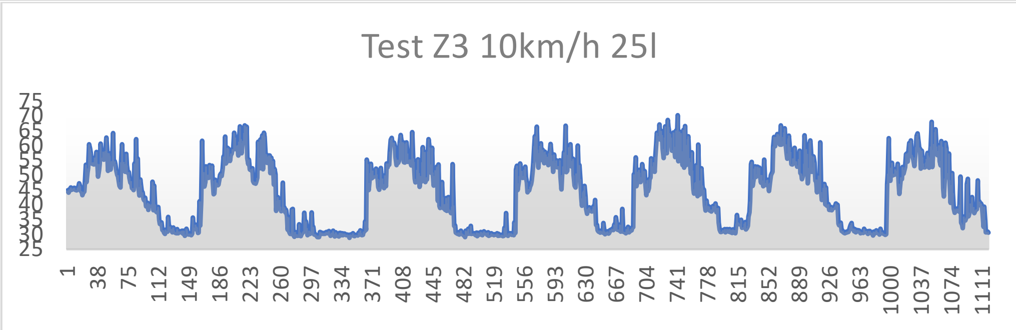
Second simulation is done according to parameters in table 1. Results can be seen in Graphic 3 with a clear difference of variation compared with previous simulation even if the waves still exist.

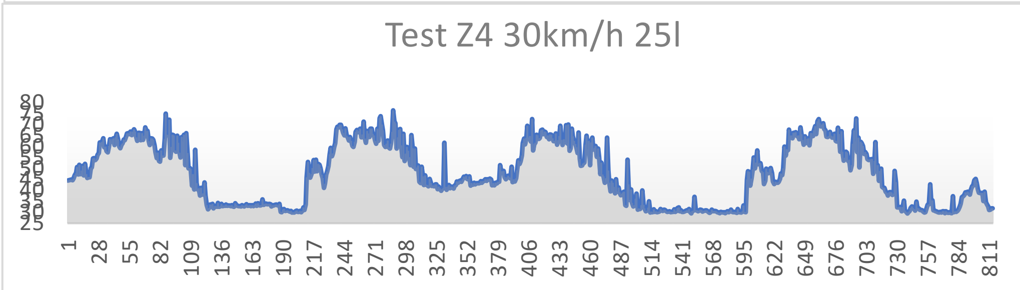


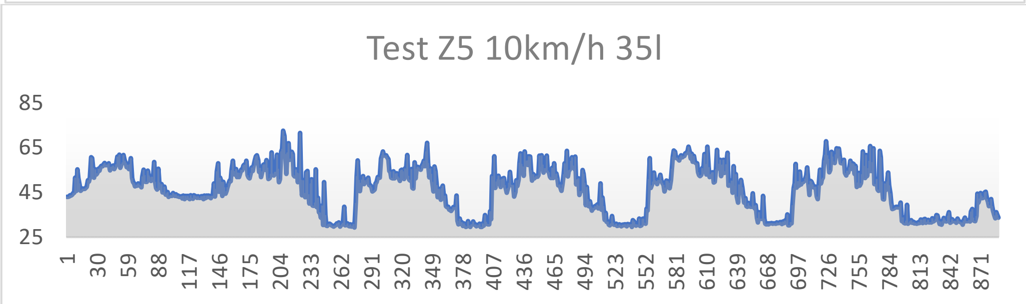
Graphic 3: Test Z1 10 Km/h 15L

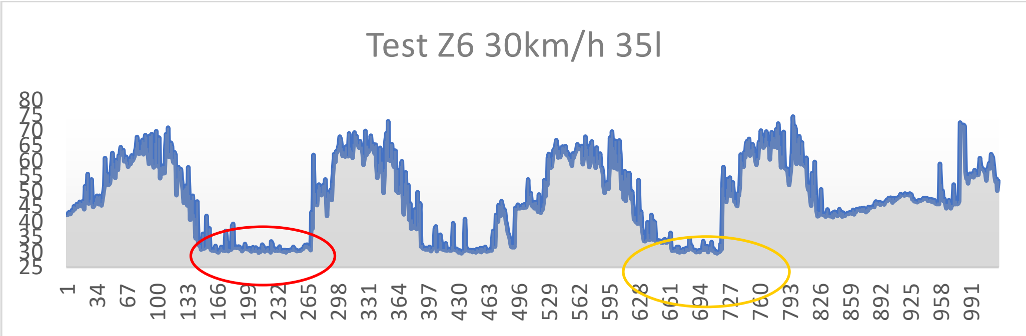
The same behavior is still observed after rising speed before braking and quantity of liquid.


Test Z2 30km/h 15l
80
75
70
65
60
55
50
45
40
35
30
25
1 18 35 52 69 86 103 120 137 154 171 188 205 222 239 256 273 290 307 324 341 358 375 392 409 426 443 460 477 494 511


Test Z3 10km/h 25l
1 38 75 112 149 186 223 260 297 334 371 408 445 482 519 556 593 630 667 704 741 778 815 852 889 926 963 1000 1037 1074 1111


Test Z4 30km/h 25l
1 28 55 82 109 136 163 190 217 244 271 298 325 352 379 406 433 460 487 514 541 568 595 622 649 676 703 730 757 784 811


Test Z5 10km/h 35l
85
65
45
25
1 30 59 88 117 146 175 204 233 262 291 320 349 378 407 436 465 494 523 552 581 610 639 668 697 726 755 784 813 842 871



Graphic 4: Test Z6 30 Km/h 15L

2.3. Data interpretation

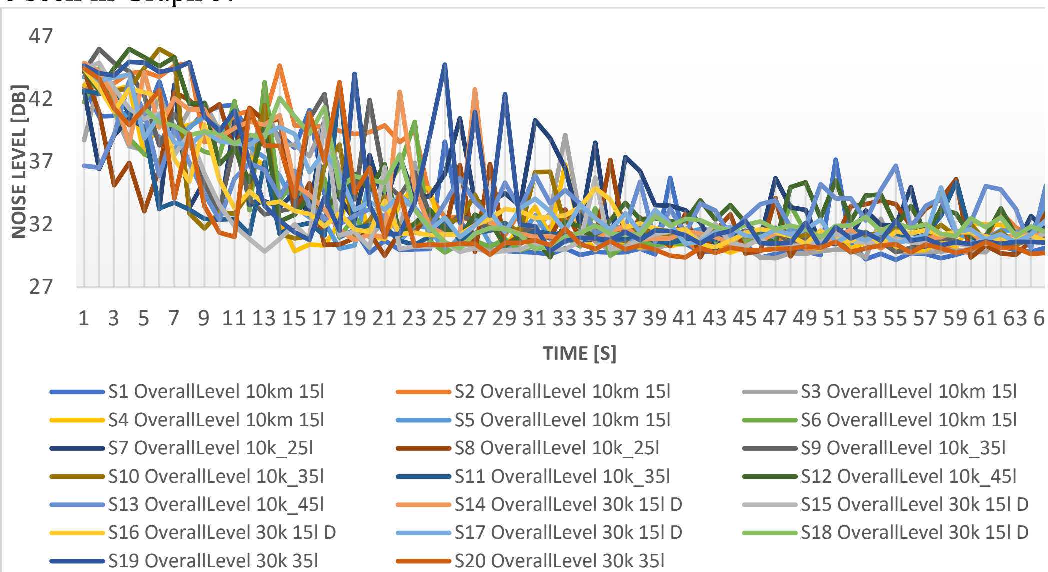
In the end, all tests were analyzed, in order to detail the decibel level variation for each case, several conclusions were made:

- Variation between 42-45 decibels in the moment of braking – influenced by waves and different external factors
- Variation between 32-45 decibels between stop engine and no other external factors, only waves movement
- Variation between 30-31 decibels represents engine stop and no waves

To determine the influence of slosh noise baffle influence in decibel level data from 32-45 decibel level will be further analyzed and compared between the two scenarios sets of data.

2.3.1. Acoustic analysis for slosh noise effect without baffle inserted

From initial set of data, 20 recordings were separated and analyzed. The results can be seen in Graph 5.



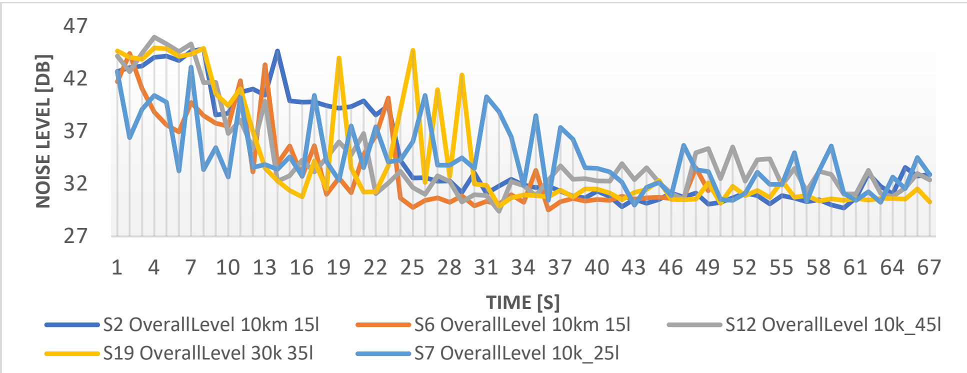
Graphic 5 Overview of 20 recordings

Data filter took in consideration usage of all parameters in Table 2 in order to distribute test negative/positive results on all cases. The result is analyzed from variation standard deviation and Mean values in order to determine worst case. For further analysis we will consider test S2, S19, S12, S6 and S7. Worst case result is highlighted in below table and graphic. Also, with no baffle inside the tank we can observe that the decibel level is high in all cases regarding liquid quantity and speed.

Table 2

Overview of test results S1-S20

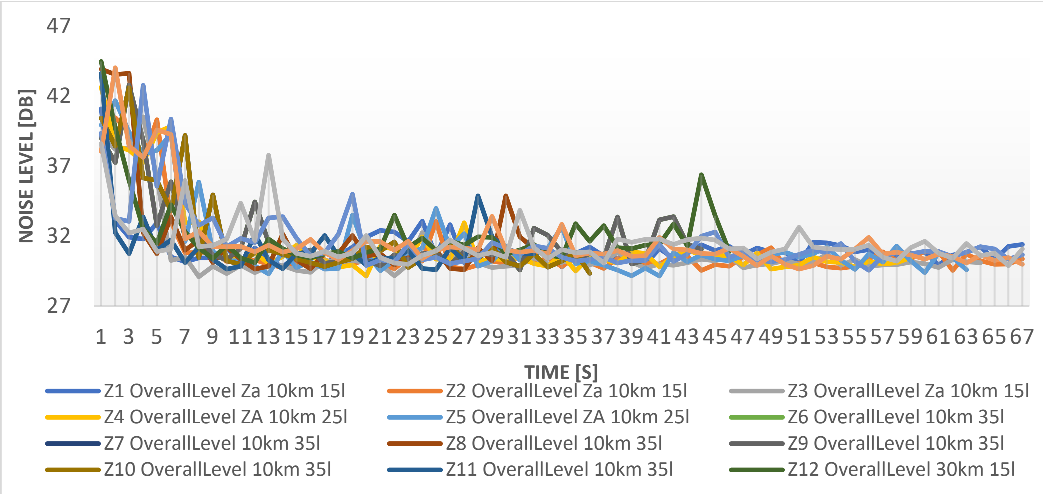
Test	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Standard deviation	4.67	5.02	4.43	3.99	3.70	4.25	3.24	3.88	4.30	4.21
Mean Value [dB]	32.91	34.76	33.38	32.99	33.13	33.78	34.44	33.50	33.50	33.42
Test	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Standard deviation	3.20	4.26	2.41	4.52	3.87	3.45	3.84	3.99	5.19	4.36
Mean Value [dB]	32.48	34.43	34.12	33.75	32.35	33.13	34.02	34.19	34.19	32.69



Graphic 6. Most representative curves – noise level with no baffle

2.3.2. Acoustic analysis for slosh noise effect with baffle inserted

Analyzed data is presented in Graph 7. It can be seen that the curves have less variation and also a more uniform level of decibels, clearly an impact of the baffle to the slosh noise effect.



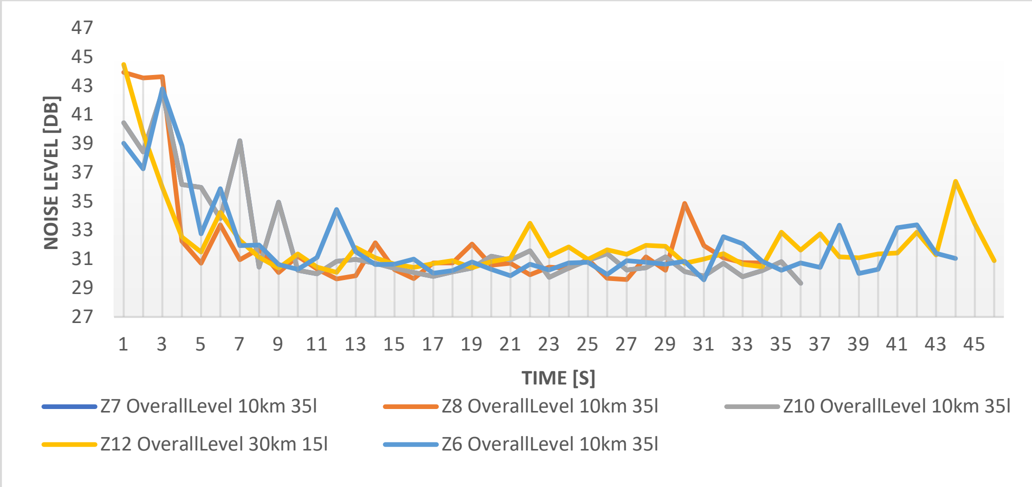
Graphic 7 – Decibel level inside fuel tank with baffle

Making the same centralization as previous case, we can see that the average values are decreasing and also the standard deviation has much smaller values. Still, we need to consider the worst case, looking at the data we can see that the baffle has an impact in noise level when used with more liquid quantity in the fuel tank. In this case the "worst case" represents low speed with higher quantity of fuel, test Z6, Z7, Z8, Z10, Z12 are considered for further analysis.

Table 3

Overview test results Z1-Z15 with link baffle

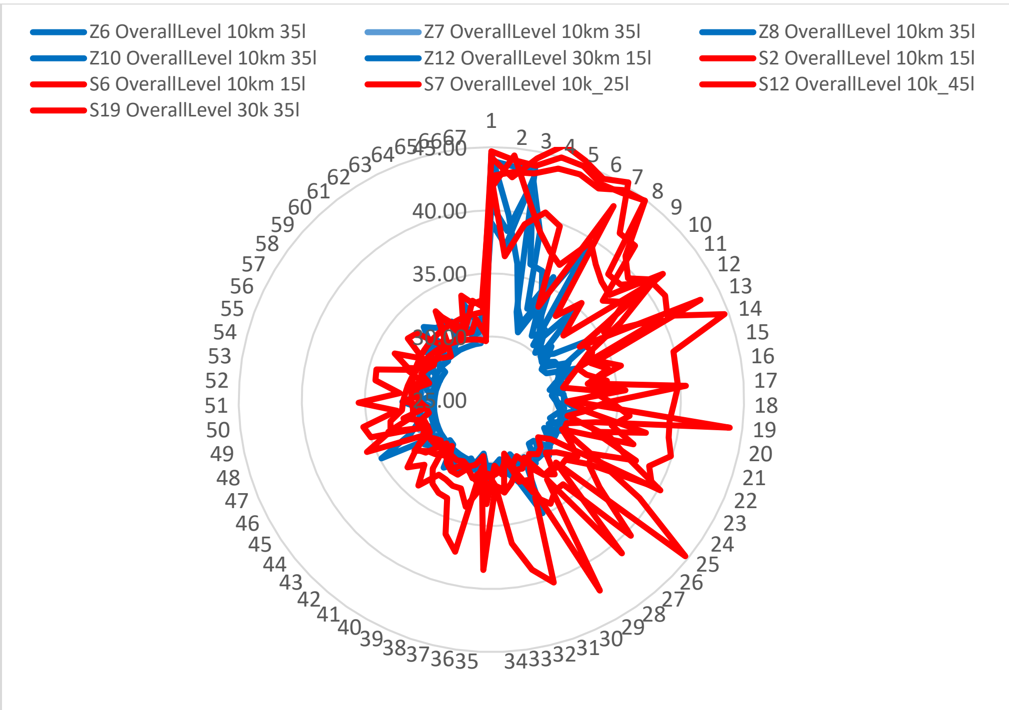
Test	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8
Standard deviation	1.45	2.50	2.35	2.84	2.85	2.79	3.37	3.84
Mean Value [dB]	31.11	30.96	30.73	31.38	31.44	31.97	32.06	32.05
Test	Z9	Z10	Z11	Z12	Z13	Z14	Z15	
Standard deviation	2.79	3.37	2.51	2.57	2.37	2.63	1.56	
Mean Value [dB]	31.97	32.06	31.32	32.12	31.61	31.69	31.49	



Graphic 8 Most representative curves – noise level with link baffle inside the tank

2.3.3. Acoustic analyze – effect of baffle introduction inside a fuel tank

Making the same centralization as in the previous case, we can see that the average values are decreasing.



Graphic 9 Comparison between with / without baffle noise results

In the radar graphic it is showed in a simple graphical way that all the tests start from the same decibel level and that the baffle test (blue) in comparison with no baffle test (red) has a better behavior regarding noise, noise variation and also the time to reach lower values of decibels. Use of "Link Baffle" doesn't permit the liquid wave to grow in amplitude inside the tank in the moment the antivehicle is stopped.

Table 4.

Statistical analysis for the 5 most representative test results

Test	**S2**	**S6**	**S7**	**S12**	**S19**	**Z6**	**Z7**	**Z8**	**Z10**	**Z12**
Speed [Km / h]	10	10	10	10	30	10	10	10	10	30
Liquid quantity [L]	15	15	25	45	35	35	35	35	35	15
Standard deviation	5.02	4.25	3.24	4.26	5.19	2.79	3.37	3.84	3.37	2.57
Mean	34.76	33.78	34.44	34.43	34.19	31.97	32.06	32.05	32.06	32.12

3. Conclusions

Several interesting aspects are concluded with this study by centralizing the data from the 5 worst case test results from each trial.

- Link baffle reduces the noise decibel level created by the liquid wave around 65%.
- If no baffle is used, the highest decibel level is recorded in test with 10km/h and 15l (34.7 dB).
- Using Link baffle, the decibel level is significant decreased for test with 10km/h and 15l liquid in tank – (31.1 dB).

By introducing the Baffle in the fuel tank, shows a reduction of the decibel level, considered as reducing the Slosh Noise Phenomena, that represents the noise produced by waves inside a tank. Study is required to present the reduction of the wave amplitude in a fuel tank that can also present multiple future applications of the study [13]. Also, the study presents opportunity for future study regards relative equilibrium of a liquid in a tank.

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