BENCHMARKING OF FOUR CYLINDER VERSUS DOWNSIZED ENGINE NOISE IN OPERATIONAL CONDITIONS

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One of the most recent trends in the European car industry has been the wide introduction of small downsized engines, i.e. small engines with low capacity and less than four cylinders. The novelty of such engines has led to uncertainties about their actual NVH behaviour and requires some deeper investigation. This paper shows an experimental comparison among the on-road NVH performance of several cars carrying respectively small downsized engines and their four cylinder counterparts in order to draw a clearer picture about this important subject for NVH engineers and end users.
Keywords: Downsized, Engine, Noise, NVH, Vehicle

1. Introduction

The increasingly demanding legislation aiming at reducing carbon dioxide emissions and fuel consumption has pushed the automotive industry towards engine downsizing, i.e. the replacement of large aspirated engines by smaller (and very often turbocharged) engines with less cylinders and capacity [1][2][3]. This has become a main trend in recent years for passenger cars and has reached its highest peak in Europe, where several car makers have successfully introduced on the market three and two cylinder engines with capacity of one liter or less [4][5][6][7].

This has raised some concerns from the beginning of the development work about a possible noise emission increase from the new downsized engines [8][9][10][11] and has prompted the development of different dedicated NVH (Noise, Vibration and Harshness) countermeasures, like for example balancing shafts or counterbalanced flywheels [5][6][12][13][14], which are not always present in four cylinder engines.

Such concerns were also often related to the basic assumption that car makers would have kept the power of their small downsized engines (at the time newly developed or still under development) at the same level as the already existing four cylinder ones. Looking at the engines sold on today’s European car market however, this does not seem the case in general (see next sections).

In the end, with so many different downsized engine versions from several different brands currently existing on the market, it is not straightforward to understand a priori the acoustic performance of the novel downsized engine generation without some specifically dedicated test work.

In particular, it is interesting to assess how effectively car makers have been able to cope with possible important noise emission issues from the new downsized engines under practical operational conditions, and where those engines position themselves in terms of acoustic performance in comparison to the four cylinder engines of the same brand.

In an attempt to help the clarification of this topic, this paper shows an on-road experimental investigation comparing several of the most recently introduced small downsized engines against their four cylinder counterparts.
2. Selection of the test cars

In order to compare the acoustic performance of different engines under operational conditions as realistically as possible, it is necessary to take into account some preliminary basic considerations. First of all, a proper selection of the cars to be tested must be done. It is necessary to identify car models carrying both the four cylinder and the downsized engine versions. Ideally, for a given car, different engine versions mounted on the same body should be tested, however taking a single car body and changing the engine among different tests is an extremely difficult, time consuming and cumbersome job. For this reason, it is much more convenient in practice to test “nominally same” cars instead, i.e. different cars with nominally the same body and accessories, and to assume that the possible influence of their structural differences on the acoustic results is not relevant.

In addition to that, it is also important that the nominally same cars selected for the test have as much as possible the same gearbox to avoid large transmission ratio mismatches, which may cause remarkably different loads on the engine at the same rotation speed. Thus, for example, it should be avoided to compare a car with a manual gearbox to another with an automatic gearbox.

Once a suitable test car model has been identified, it is also highly recommendable to select single cars carrying the same engine bay body-mounted acoustic treatment at least in proximity of the microphones (e.g. hoodliner, outer dash insulator, waterbox insulator) in order to avoid that the Sound Pressure Level (SPL) measurement results in the engine bay get affected by possible differences in the engine compartment boundary conditions.

Bearing the above-mentioned selection criteria in mind, a total of eight suitable car models from eight different representative car makers on the European market have been identified. Each car model comes with at least one four cylinder and one downsized engine version. Two of the selected car models belong to the C segment (compact), three to the B segment (sub-compact), and three to the A segment (mini). All the car models and engine versions selected within the frame of this work are currently on the road in Europe. The fuel for all the tested engines is gasoline RON 95.

Tables 1 to 3 give an overview of the selected cars with their respective engines. Each engine is identified by the capital letter I (meaning “in-line cylinders”) followed by a digit (respectively 2, 3 or 4) corresponding to the number of cylinders. The capacity and the maximum output power of each engine are also reported. When possible, more than two engine versions for a given car have been selected. A total of nineteen cars have been tested.

| Car | C segment cars | | | |
|-----|----------------|----------------|----------------|
| Engine | I3 | I4 | I3 | I4 |
| No. of cylinders | 3 | 4 | 3 | 4 |
| Capacity [liters] | 1.5 | 1.6 | 1.0 | 1.6 |
| Power [HP] | 109 | 136 | 125 | 150 |

Table 1: C segment cars and corresponding engines

<table>
<thead>
<tr>
<th>Car</th>
<th>B segment cars</th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Engine</td>
<td>I3</td>
<td>I4-95</td>
<td>I4-120</td>
<td>I3</td>
</tr>
<tr>
<td>No. of cylinders</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Capacity [liters]</td>
<td>1.2</td>
<td>1.4</td>
<td>1.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Power [HP]</td>
<td>82</td>
<td>95</td>
<td>120</td>
<td>90</td>
</tr>
</tbody>
</table>

Table 2: B segment cars and corresponding engines
3. Experimental test

All tests have been carried out on the same road stretch paved with smooth asphalt under wide open throttle (WOT) acceleration conditions in second gear. This test condition ensures the clear dominance of engine noise above the other main noise sources like tyres and wind.

The SPL has been recorded in the car engine bay and interior passenger compartment by means of microphones. Fig. 1 shows an overview of the microphone positions. Three microphones are positioned in the engine bay on the main noise path from the engine towards the outer dashboard, respectively in the middle, on the left and on the right side of the outer dash panel. In addition, two more microphones are placed at the front passenger position, one at the left and one at the right ear. According to Autoneum standard, the microphones at the front passenger position are mounted on a dummy head and torso placed on the respective seat to better take into account near sound field effects. The SPL curves in the engine bay and in the interior compartment are found as the average over five different acceleration run-ups of the recorded SPL respectively at the three microphone positions before the outer dash and the two at the front passenger ears.

![Experimental setup: sketch of microphone positions and dummy](image)

4. Experimental results

The next Fig. 2 to Fig. 9 show the SPL measurement results of the eight car models under test. Each figure belongs to a specific car model and shows from left to right respectively: the measured SPL in the engine bay against the engine rotation in revolutions per minute (RPM), the same SPL against the car speed in km per hour (kph), and the SPL at the front passenger position against the car speed in kph.

It must be remarked that, while a lot of care has been taken in keeping as much as possible identical boundary conditions in the engine bay, the same cannot be completely assured for the passenger compartment. In fact, although the car seats and the other visible interior compartment surfaces do not differ from one engine configuration to the other of the same car model, a question mark can be raised about the inner dash insulator technology and pass-through configuration, which can be different from one engine version to another.

<table>
<thead>
<tr>
<th>Car</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>I3</td>
<td>I4</td>
<td>I2</td>
</tr>
<tr>
<td>No. of cylinders</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Capacity [liters]</td>
<td>1.0</td>
<td>1.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Power [HP]</td>
<td>67</td>
<td>87</td>
<td>85</td>
</tr>
</tbody>
</table>

Table 3: A segment cars and corresponding engines
For example, the inner dash insulator technology of car A2 highly depends on the engine version. The car body with the four cylinder engine carries an absorption type lightweight insulator entirely made of recycled felt, while the same body with the downsized engine carries a spring-mass insulator with a heavyweight barrier layer. Some further differences can also be found in the pass-through (grommet) number, area, and shape.

All in all, checking the possible discrepancies among the inner dashes corresponding to the different engine versions of all the tested vehicles is a very difficult and time consuming task. Moreover, possible differences on the inner dash cannot be eliminated and can affect the interior compartment noise level in a non-negligible way. For this reason the SPL measured in the passenger compartment, although interesting to be checked, cannot be taken as representative of the noise level directly coming from the engine, and the main reference to judge the acoustic performance of the different engines under test remains the measured SPL in the engine bay.

For what concerns the C segment cars, the downsized engines have notably less power and at the same time a slight overall advantage in terms of emitted noise in comparison to the four cylinder ones. For the A and B segments, the comparisons show different trends depending on the analyzed car. In the case of car B1, the downsized engine is remarkably less powerful and at the same time performs clearly better acoustically than the four cylinder versions.

For cars B2 and A1, there is a rather even trade between the three and four cylinder engines in spite of the downsized engine being less powerful. Car B3 on the contrary has a less noisy three cylinder engine with a power value between the two different four cylinder versions under comparison. Car A2 is the only case where a more powerful downsized engine is also noisier than a less powerful four cylinder one. For car A3, two downsized engine versions could be tested, one more and one less powerful than the four cylinder engine mounted on the same car, and both show globally better acoustic performance.

Fig. 2: Car C1 test results

Fig. 3: Car C2 test results

Fig. 4: Car B1 test results
Fig. 10 summarizes the test results at a glance. On the left side, the measured SPL in the engine bay averaged across the RPM range is displayed against the maximum output power of each engine. Generally speaking, it can be noticed that the downsized engines tend to be concentrated on the chart lower end (lower average noise), while on the contrary the four cylinder engines rather appear on the upper end (higher average noise).

The chart on the right side shows the so-called “downsizing direction” for each investigated car model, i.e. where the downsized engines have ended up in terms of average emitted noise and pow-
er starting from the position in the chart of their respective (typically pre-existing) four cylinder homologues on the same car.

It can be seen that all but one downsized engines are globally less noisy, and all but two have lower power levels. It can also be noticed that there seems to be a roughly direct proportionality between the power level and the measured average SPL independently on the engine type.

![Fig. 10: Average SPL vs. power and downsizing directions for the investigated engines](image)

5. Conclusions

From the investigation presented in this paper, it is possible to see that, in comparison with existing four cylinder engines, car makers have reduced in general not only the capacity but also the power of the new downsized engines that they have developed.

Although some NVH concerns might have arisen during the development work, in the end the experimental results show that car makers have mostly succeeded in keeping the emitted noise of the new downsized engines in real operational conditions at lower levels in comparison to higher capacity four cylinder engines mounted on the same car.

The experimental results have also confirmed that, as an empirical rule of thumb, the maximum engine output power and the noise in the engine bay roughly follow each other independently on the number of cylinders and capacity of a specific engine.

Thus, being most of the analyzed downsized engines less powerful than their four cylinder counterparts on the same car, in the end it is rather natural to find that they are also less noisy.

In general, and especially in the minority of cases when higher emitted noise from a downsized engine occurs, car makers clearly seem to have adopted sufficient NVH countermeasures at body level in order to achieve acceptable interior noise performance in comparison to a standard four cylinder engine on the same car.

It is worthwhile to mention that the experimental results and trends shown in this paper might differ from those of a possible subjective assessment of the investigated cars. In fact, the typical downsized engine average usage implies driving at higher RPM ranges than a four cylinder engine mounted on the same car to achieve the same performance. This could be the cause of some possible subjective acoustics deterioration under the same driving conditions. For this reason, it would be premature to draw conclusions about the subjective engine noise perception in the tested cars only on the basis of the noise measurement campaign described in this paper.
REFERENCES


