# Fast and Brand-Specific Calibration of Fuel-efficient Powertrains

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## Abstract

Future emission legislation requirements especially the need for $CO_2$ reduction lead to more complex powertrain concepts with an increasing number of independent parameters to be calibrated. For gasoline engines concepts with variable valve timing, direct injection or variable charge motion are in development or already on production. Diesel engines with common rail systems offer a wide range of new injection strategies, the application of new exhaust aftertreatment systems leads to additional complexity. Furthermore a clear trend to highly sophisticated transmission concepts requires a perfect interaction of all powertrain components.

While the higher complexity requires increasing test and development effort, the development duration is reduced significantly. Consequently, the potential of such systems cannot be fully utilised by traditional development and calibration approaches within the given timeframe. By introduction of intelligent methodologies for the calibration of modern powertrains the development becomes more efficient, faster and better in quality. However, even with standardised and automated calibration methods a differentiated brand-specific powertrain character has to be maintained comparable to a "handmade" calibration performed by highly experienced experts.

## 1. The challenge

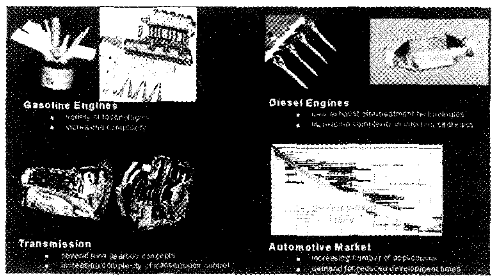
The challenge for Automotive $CO_2$ reduction is the main driver for the development of new powertrain concepts. Additionally future legislation will require a further reduction of vehicle emissions - especially for Diesel engines new exhaust aftertreatment systems will be needed. Traditional development targets like performance or production costs have influence on technology decisions as well.

For Gasoline engines different technologies like fully or partly variable valve trains, direct injection, variable charge motion or downsizing are in development or already in production to reduce fuel consumption. New technologies like electro-hydraulic valve actuation systems or homogeneous compression ignition are currently in an advanced development status. The technology choice depends very much on the vehicle class but also on the manufacturer's image and strategy. Most likely various Gasoline engine concepts will exist in parallel also in the near future, in any case the complexity will increase.

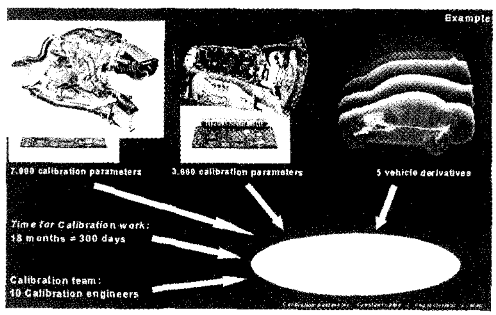
For Diesel engines the technology trend seems to be more clear, direct injection with common rail or unit injector systems is "state of the art". Nevertheless the complexity is similar to Gasoline engines as advanced Diesel injection equipment offers new injection strategies with pre and post injections. Additional challenge comes up with particulate filters, which may become a standard for the majority of Diesel powertrains in the near future. To meet the stringent emissions requirements new technologies like DeNOx catalyst are currently under investigation.

In the field of transmissions, where the technology was quite stable during the last decades, completely new concepts have entered the market recently. Continuous variable transmissions, robotised gearboxes and double clutch transmissions have gone to production or are very close to. Even the traditional manual gearboxes and automatic transmi-ssions with torque converter become more and more sophisticated.

The new transmission concepts have significant potential in fuel consumption reduction and offer new shifting strategies with a different, in some cases unusual driveability. To meet customer's expectation benefits cannot always be fully utilised, a sufficient trade-off has to be found during the calibration.




〈Figure 1〉 High Complexity of Modern Powertrains and Market Trends Lead to Increasing Calibration Challenge

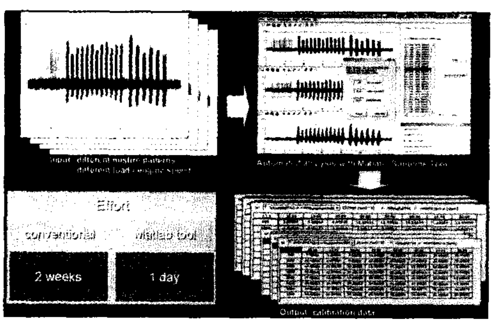



〈Figure 2〉 Calibration of Modern Powertrains is not Longer Possible with Traditional Methods air/fuel-ratio and cam-phasing of a direct injection Gasoline engine, which did not have any basic calibration. For that purpose a "combustion controller" and an exhaust gas temperature controller were integrated in the test bed and calibration environment.

Such procedures are currently used successfully at AVL for advanced projects. They will find their way into standard calibration methodology in the near future.

Of course all test bed automation routines require highest standards of the test bed environment. Additional safety measures are necessary to allow automated, unmanned test procedures. For example such methods mostly require full pressure indication. Accuracy, and reproducibility have to fulfil highest demands.

Besides the afore-mentioned methods for improving efficiency in the test bed calibration process AVL has established evaluation routines for several other calibration tasks. These routines are usually based on Matlab and support the automated analysis of test bed and vehicle measurements as well as the automated generation of calibration data.




〈Figure 6〉 Automated Analysis and Generation of Calibration Data for Gasoline OBD Misfire Detection

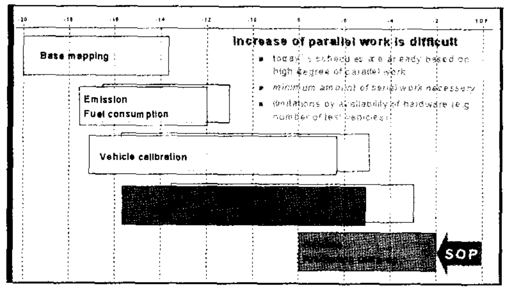
For example a Matlab routine was developed and introduced to analyse the huge amount of test data, which comes up during the calibration of the misfire monitoring. This routine automatically generates threshold maps on the basis of the measurements performed in the vehicle under misfiring conditions. Furthermore, the tool provides an assessment of the detection quality and calculates the misfire capability tables.

### 〉〉〉〉 Increased degree of parallel work

Today's development schedules are already based on a high degree of parallel work. Since many tasks require input from previous development steps there is a natural limit for further increase of parallel work.

Furthermore, the increasing development cost pressure requires a reduction of testing hardware like prototype test vehicles. Therefore an increase of parallel work is counterproductive for many hardware-related tasks.

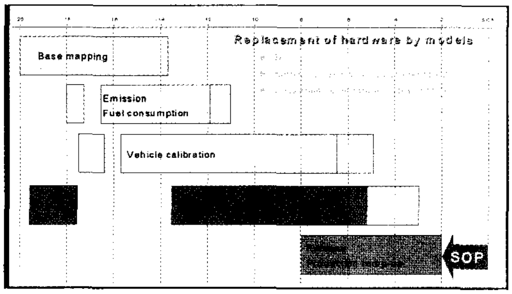
As a consequence the idea of further increase of parallel working offers only little time-saving potential.




〈Figure 7〉 Reduction of Calibration Time by Increasing the Degree of Parallel Work

### 〉〉〉 Earlier start of calibration work

To start the calibration work earlier requires in many cases to start before the respective hardware is available. Consequently that leads to new calibration methods, missing hardware has to be replaced by sophisticated models.




〈Figure 8〉 Reduction of Calibration Time by Starting Single Tasks Earlier Even Wihout Hardware

A very popular and well-known approach is the use of hardware in the loop (HIL). While the use of HIL has become a standard procedure for testing control unit hardware and software, the full potential of the "virtual calibration" is by far not utilised yet. The necessary models are usually quite complex, real-time calculation is partly limited by computing performance.

Virtual calibration will allow starting the calibration work before the first engine is available on the test bed. Moreover some tasks that traditionally were extremely hardware-intensive may be performed with reduced hardware effort. One example will be the reduction of cold tests by performing parts of the cold calibration on a real-time engine model.

The virtual calibration offers a huge potential for saving time and development costs. The necessary models are currently under development, however, it will take some time before such methods will be become a standard in the calibration process.

Another approach is to shift vehicle work to an earlier phase of the calibration process, that means to the phase of test bed calibration. That gains time in the vehicle calibration phase and therefore reduces the time between availability of the first vehicle and the start of production.

Besides the timing benefit this approach allows the replacement of extremely expensive prototype vehicles by comparatively cheap engines.

The rough calibration of emissions on the dynamic test bed has become a standard procedure during the last years. Devices for a quick cool-down immediately after the emission test cycle allow several emission tests a day. Consequently the time for emission optimisation can be reduced.

Especially the investigation of parameter variations and their influence on emission results can be performed quicker and with a higher repeatability. Of course the verification of the results and the fine-tuning of the emission calibration is still a matter of traditional vehicle and chassis dynamometer work.

Another advanced approach that was introduced at AVL recently is the pre-calibration of driveability on a high dynamic test bed. This approach reduces the total time needed for driveability calibration. In comparison with traditional calibration an equal or even improved calibration quality is achieved. Moreover, the calibration time in the vehicle is reduced significantly, that allows to reduce the number of expensive test vehicles.

## 3. Keep the brand

The automotive competition has become very tough during the past years. Nearly every manufacturer is represented in every market niche. Based on platform strategies similar powertrains are installed in vehicles with a different image. In parallel the customer behaviour has changed: compared to former days, customers are not strongly linked to certain brands, they easily change.

Consequently a clear and differentiated brand image is of high importance. Besides design the powertrain characteristics have major impact on the vehicle's image. Sound and driveability are important ingredients of the vehicle character.

The use of standard calibration methods to reduce the time may lead to similar results on different applications. That leads to a certain risk of loosing brand specific powertrain behaviour if similar or equal methods are used at different OEMs or if the calibration is performed by external parties like Tier 1 suppliers or engineering companies.

Therefore the development of new calibration methodology must not only focus on gaining development time but also on measures that guarantee a brand specific calibration result.

The following approaches support the achievement of the desired powertrain behaviour:

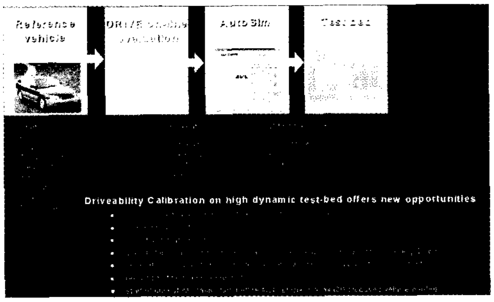
1. Tools for objective assessment of driveability and sound quality and consequent utilisation of such methods during the entire calibration process
2. Development of special control unit software specifically design for the respective vehicle brand

### 》》》 Methods for objective assessment

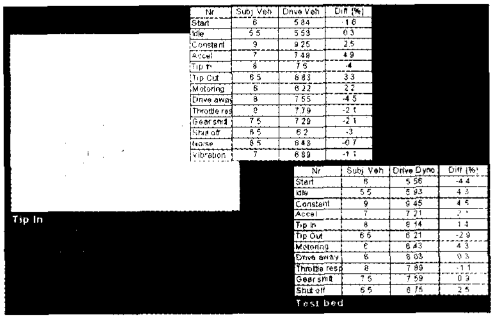
By means of a real-time tool for objective assessment of the powertrain behaviour both targets - time reduction and brand specific calibration - can be achieved. The distinct voting of such a tool allows the precise assessment of all calibration changes, even if the impact on the result is very little (e.g. during the fine tuning phase). Furthermore calibration engineers become independent from the highly skilled and experienced driveability experts, whose availability is usually quite limited.

AVL's pre-calibration of driveability on the high dynamic test bed perfectly combines these opportunities with advanced time-saving calibration methods. Besides the objective assessment tool AVL DRIVE this approach requires a high quality dynamic test bed and a perfect vehicle model to generate real-time vehicle signals like longitudinal acceleration.

The high reproducibility and the opportunity to make use of automated calibration methods




〈Figure 9〉 Driveability Calibratin on the Test Bed Combines Fast and Brand-Specific Calibration Methods




| Nr | Subj Veh | Drive Veh | Diff [%] |
|---|---|---|---|
| Start | 6 | 5 84 | -1 6 |
| Idle | 5 5 | 5 53 | 0 3 |
| Constant | 9 | 9 25 | 2 5 |
| Accel | 7 | 7 49 | 4 9 |
| Tip In | 8 | 7 5 | -4 |
| Tip Out | 6 5 | 6 83 | 3 3 |
| Motoring | 6 | 6 22 | 2 2 |
| Drive away | 8 | 7 55 | -4 5 |
| Throttle res | 8 | 7 79 | -2 1 |
| Gear shift | 7 5 | 7 29 | -2 1 |
| Shut off | 6 5 | 6 2 | -3 |
| Noise | 8 5 | 8 43 | -0 7 |
| Vibration | 7 | 6 89 | -1 1 |

| Nr | Subj Veh | Drive Dyno | Diff [%] |
|---|---|---|---|
| Start | 6 | 5 56 | -4 4 |
| Idle | 5 5 | 5 93 | 4 3 |
| Constant | 9 | 9 45 | 4 5 |
| Accel | 7 | 7 21 | [illegible] |
| Tip In | 8 | 8 14 | 1 4 |
| Tip Out | 6 5 | 6 21 | -2 9 |
| Motoring | 6 | 6 43 | 4 3 |
| Drive away | 8 | 8 03 | 0 3 |
| Throttle resp | 8 | 7 89 | -1 1 |
| Gear shift | 7 5 | 7 59 | 0 9 |
| Shut off | 6 5 | 6 75 | 2 5 |

〈Figure 10〉 Comparison of Calibration on Test Bed and in Vehicle Gives Good Correlation

combine a significant reduction of needed calibration time with equal or even improved calibration quality. Driveability calibration may start earlier, even in a phase when no vehicle is available.

As modern ECU-systems offer an enormous number of driveability calibration parameters, the biggest benefit of course is the chance to use DoE methods. The impact of different calibration strategies can be investigated easily, the relationship between the calibration parameters may be visualised and optimised by means of the resulting models. Once the models are available "off-line" fine tuning of driveability is possible.

As an additional benefit that approach allows to create different driveability calibrations without additional testing effort. That gives the opportunity to compare quickly different vehicle characters e.g. a sporty or a more comfort-oriented calibration.

### 〉〉〉〉 Specific control unit software

As the powertrain behaviour heavily depends on the control unit software a brand-specific calibration is limited to the opportunities within the control logic. The development of brand-specific software modules, that are operated on a state-of-the-art software basis, offer differentiated calibration strategies. In that understanding software development offers added value to the customer.

Typical examples are OEM-specific driveability functions within engine control units or self-adaptive gear shifting strategies in advanced transmission control units.

## 4. Conclusion

The requirements for reduced fuel consumption and low emissions have started a trend towards powertrain concepts with increasing complexity. The calibration of advanced powertrain control units becomes more and more challenging. Therefore the introduction of new calibration methods is not longer an option but a must to fulfil today's and future requirements on development time, development costs and quality.

Development of calibration methodology has to concentrate on gaining development time and on measures to guarantee brand-specific calibration results.

Several new calibration methods have already been introduced successfully. By use of AVL CAMEO - including DoE routines - the calibration process could be optimised, significant time reduction has already been achieved for several calibration tasks. The unique tool AVL DRIVE has been established to guarantee a continuous brand-specific approach during the entire powertrain calibration process.

One consequent continuation of this strategy is the combination of CAMEO, DRIVE and DoE for driveability calibration on the highly dynamic test bed. This trend-setting approach allows an earlier start of the driveability calibration and therefore offers huge time saving potential. Consequently test vehicles can be reduced, which leads to interesting options for reduced development budgets.

However, a continuous extension and further development of calibration methods is necessary, this will require increasing effort in the future. Single optimisation measures have to be combined in a proper and holistic way to make maximum use of the possible benefits.

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