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Guided and automated calibration and validation of powertrain systems

Powertrain system calibration and validation faces multiple challenges. These include complex electronically controlled systems with elaborate embedded software that are used in multiple vehicle variants; demanding requirements regarding pollutant emissions, fuel consumption, and on-board diagnostics; limited numbers of test vehicles; and strict quality targets coupled with ever shorter development cycles. These complex factors make it more important than ever to standardize the procedures involved.

Computer-assisted simulations as well as data analysis and regulation optimization techniques considerably reduce the effort required for the recording and analysis of measured data and the calibration of ECU parameters.

INCA-FLOW increases calibration and validation efficiency

In the past, the task of automating calibration and validation procedures involved scripting languages or tools that could only be used by software experts with specific programming skills. To enable calibration and test engineers to automate complex workflows themselves, ETAS and IAV developed the INCA-FLOW software tool. INCA-FLOW facilitates the graphical specification of measurement and calibration procedures in the form of flow diagrams.

Flow diagrams created using INCA-FLOW serve as a resource for generating procedures that can either be used to automate measurement and calibration processes or to guide users in calibrating ECUs and validating the behavior of electronically controlled systems (Fig. 1). INCA-FLOW allows generated procedures to be imported and exported, making it easy to swap them around and distribute them. On the other hand, users can also document their procedures by saving the diagrams in HTML format.

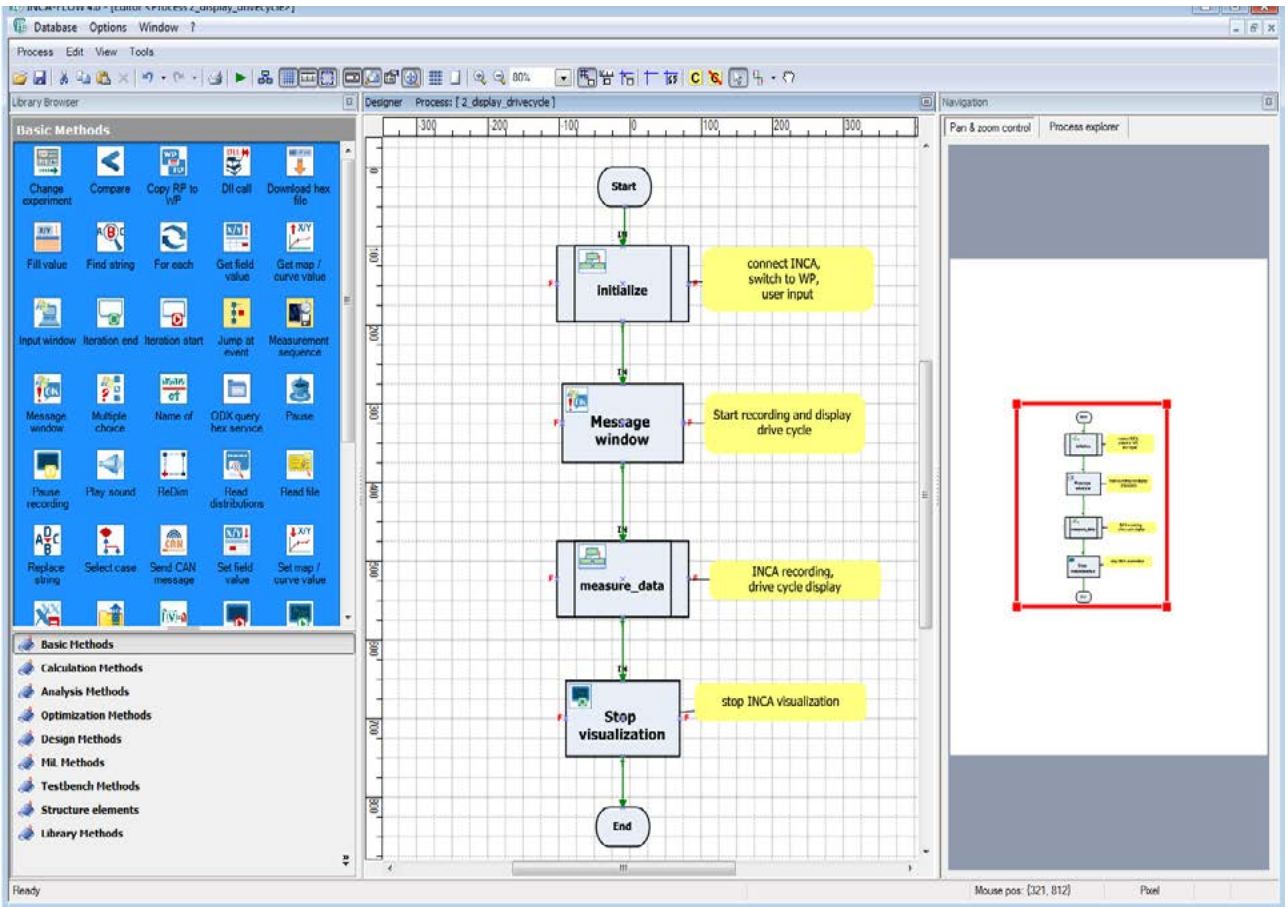
INCA-FLOW procedures – which are controlled by the ETAS INCA measurement, calibration, and diagnostic tool – make it easy to automate iterative and repetitive measurement and calibration workflows. One way in which INCA-FLOW differs from traditional approaches is that it does not confine calibration and test engineers to a rigid, predefined script. Instead, it empowers them to adapt and tailor in-vehicle procedures themselves. INCA-FLOW also provides a wide assortment of data analysis techniques. For example, the measured data extracted using filters can be analyzed as follows: by calculating the main frequency and the maximum amplitude of a measurement signal after Fast Fourier Transformation (FFT); by determining overshoot and undershoot of controls; and through statistical evaluation, including the presentation of the relevant results. Based on the results of data analyses, INCA-FLOW can be used in subsequent steps to automatically calculate parameters such as the ECU characteristic map values.

You can use INCA-FLOW to produce detailed documentation that is the perfect basis for efficiently standardizing the methods and procedures a company uses to calibrate and validate powertrain systems. Consistent standardization offers two key advantages. First, it significantly reduces the time and effort required for calibration and validation while substantially improving the quality of the results. Second, it gives a real boost to collaboration between manufacturers, suppliers, and engineering service providers by enabling them to exchange INCA-FLOW procedures in joint projects. This means engineers can make the most of their valuable time in the test vehicle by getting straight down to calibrating and validating the systems instead of having to verify the measurement and calibration procedures first.

Modification of INCA-FLOW procedures for different ECU variants

When calibrating internal combustion engines, many tasks are repeated across various projects, such as the setting of the pedal

Fig. 1: INCA-FLOW's graphical user interface. Left: selection of methods for automating the INCA measurement, calibration, and diagnostic tool, calculation methods, data analysis, optimization, support in designing function models, simulation control, and integration with test bench control systems. Center: flow diagram to guide calibration and test engineers through a test drive based on the drive cycle. Right: the zoom and navigation pane.



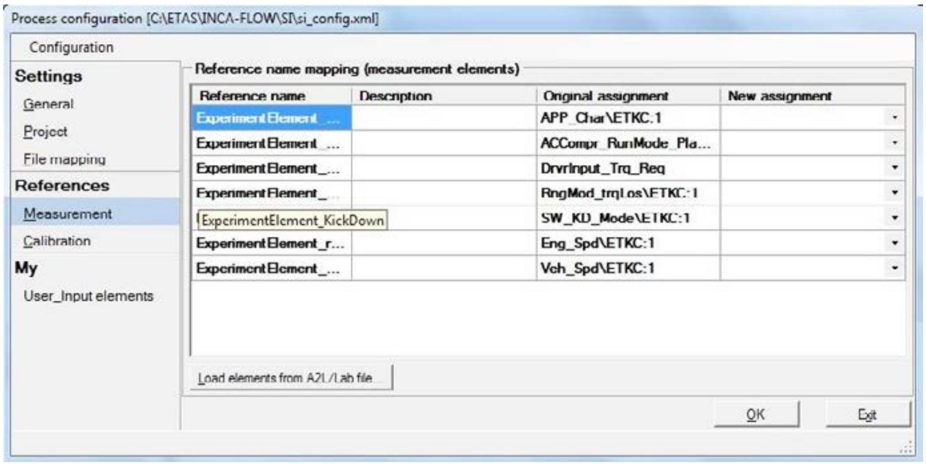


Fig. 2: INCA-FLOW's standalone configurator. The "References" tab shows a view of references of related standalone procedures based on existing measurement and calibration variables. The view shows the name of the reference and, if available, a definition of the related measurement. The description of the related measurement and calibration variables used by the INCA-FLOW procedure is added in the "Original assignment" column. Different or differently described input and output parameters can be assigned to these variables in the "New assignment" column. ASAP2 data or simple variable lists can be used for this purpose. Application-specific values can be entered under the "My" tab.

maps to optimize acceleration behavior and minimize jolting. These tasks can be easily described using INCA-FLOW. One-off procedures generated on the basis of such descriptions can be conducted on a standalone INCA computer (one without a complete INCA-FLOW installation) with the help of a runtime license. The standalone procedures can be modified to project-specific requirements using the INCA-FLOW standalone configurator (Fig. 2) and subsequently reused in related projects that use similar ECUs. This increases the efficiency of the solution (1).

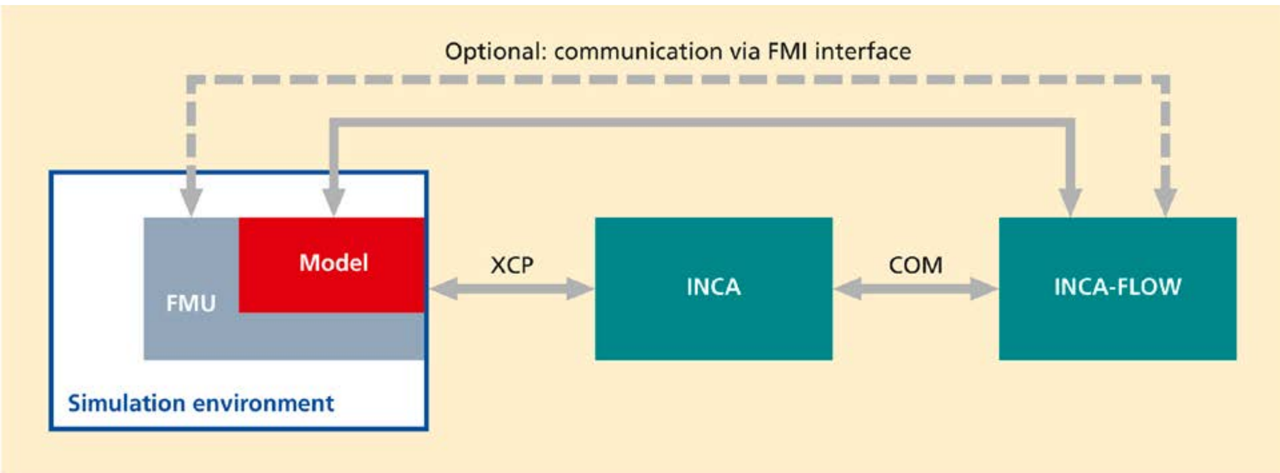
The tool can be used to enter general information such as the name of a procedure or project and any comments, or to adjust project-specific settings such as hard and soft limits for characteristic values. Meanwhile, a mapping function allows users to easily change the assignment of input and output variables in an INCA-FLOW procedure to an ECU's measurement. This means standalone procedures can also be reused in related ECU projects, even if those projects refer to project variables and parameters differently, perhaps using country-specific terms. The parameters are preset to their values in the project for which the procedure was initially created. The varying configurations defined for different projects can also be comfortably managed using the INCA-FLOW standalone configurator.

Uses outside the vehicle

To use INCA-FLOW, the following development and test environments outside the test vehicle are relevant; provided calibration and validation methods were initially described using INCA-FLOW while developing new systems and related ECU functions, they were tested in simulations or on a test bench and need to be iteratively refined:

- simulation environments
- Hardware-in-the-loop (HiL) test systems
- engine and dynamometer test bench

Fig. 3: INCA-FLOW not only uses INCA's XCP interface, but it can also stimulate models during an ongoing simulation via direct access through a proprietary or FMI interface. In the second case, the models are encapsulated in so-called functional mock-up units (FMUs), or containers with FMI interfaces. FMUs are often used for co-simulations that are developed into different, domain-specific modeling environments.



Specific plug-ins with suitable functions are available for INCA-FLOW to calibrate and validate ECU functions in these environments.

When it comes to modeling new ECU functions, INCA-FLOW benefits developers by enabling them to define suitable measurement and calibration procedures right from the start of the development process. As well as eliminating the need to produce measurement and calibration instructions in an often ambiguous text form, this also bridges the gap between the realms of function development, calibration, and test drives by enabling calibration and test engineers to tailor INCA-FLOW procedures to specific applications.

Connecting to simulation environments and HiL test systems

While working on ECU functions, developers simulate the function's behavior and test it on a computer with the help of function models. They stimulate the model either in an "open loop" with suitable input values or close the loop using a "closed loop" model, which simulates the ECU's behavior ("Model-in-the-loop", MiL).

INCA-FLOW automates open- and closed-loop tests using interfaces that meet the ASAM MCD-1 XCP (universal measurement and calibration protocol) (2) and optionally, FMI (functional mock-up interface) (3) standards. INCA can use the XCP to access the function model regardless of the specific simulation environment. In addition to automating the collection of measurement data and calibration of models with INCA while a simulation is in progress, INCA-FLOW also enables the simulation of function models via direct memory access (Fig. 3). That means simulations can be run, for example, with data collected in-vehicle from the real system.

INCA-FLOW provides its own algorithms to optimize function parameters. In addition, highly-developed optimizers can be integrated as DLLs. With INCA-FLOW, simulations can run up to

Fig. 4: Integration of INCA and INCA-FLOW in test bench environments.

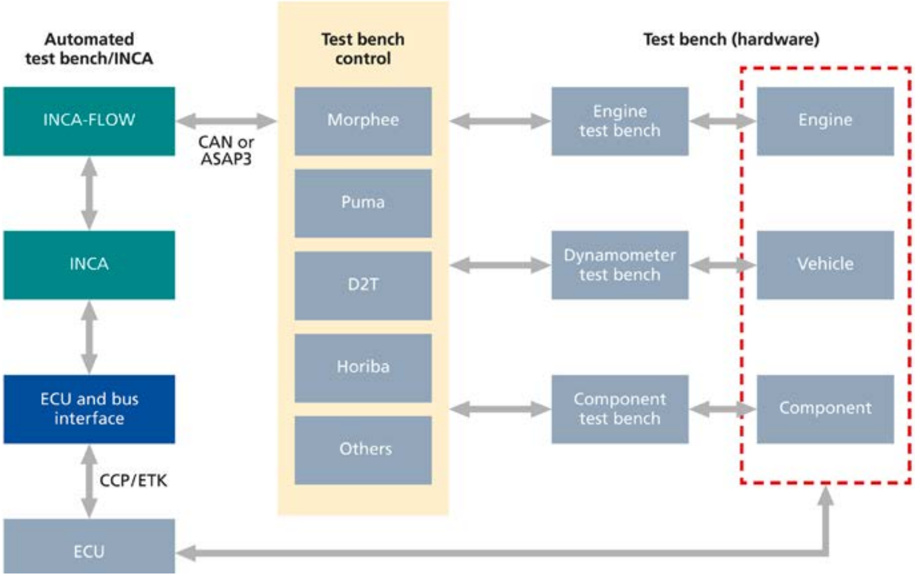
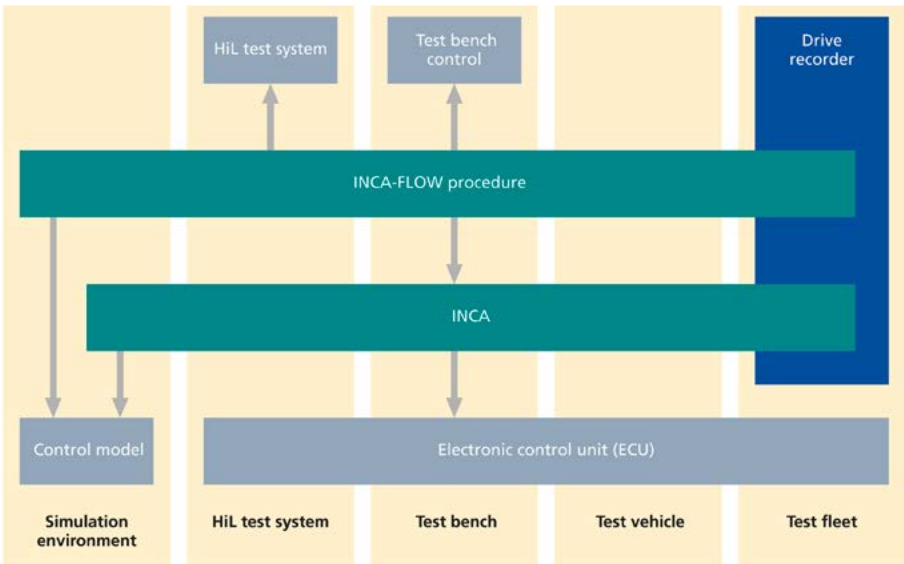


Fig. 5: INCA is used to access the ECU and/or function models in ECU calibration and validation. INCA-FLOW uses INCA to automate calibration and validation in all relevant development and test environments.



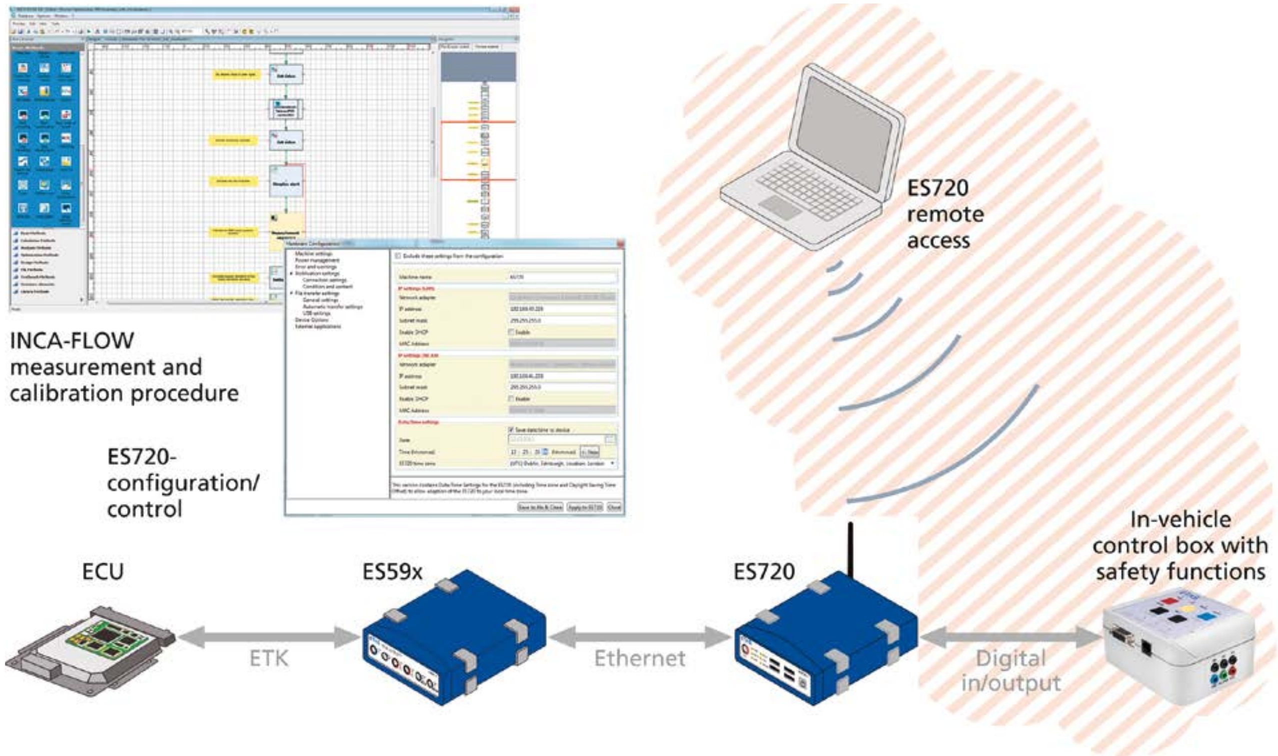


Fig. 6: Using INCA-FLOW in test fleets. The ES720 drive recorder is configured remotely. The measurements controlled by INCA-FLOW procedures are then run unsupervised on the drive recorder. The driver of the fleet vehicle releases the remote access through the control box, which provides additional safety functions in case of emergency.

a thousand times faster than in real time. INCA-FLOW offers simulation control methods like "Start MiL", "Stop MiL", "Reset MiL", and "Step MiL". In analogy to the MiL application described above, future versions of INCA-FLOW will enable the connection to HiL systems via the ASAM-XiL interface (4).

Connecting to the test bench

On the test bench, INCA-FLOW can be used as an automated system that connects to the test bench via standard interfaces such as CAN or ASAP3 (Fig. 4). The CAN connection requires specific communication data that can be stored in CAN-DBC format. To protect the communication against system failures, INCA-FLOW offers the possibility of sending "alive counter" messages on CAN to the test bench. By monitoring the reading of the alive counter, the test bench can react to failures such as communication errors. INCA-FLOW can send its own signals via the CAN interface to display complex measuring and calibration procedures, which require specific trigger or monitoring functions. Future INCA-FLOW releases will also enable communication with the test bench control via additional protocols such as XCP Gateway via INCA, ASAM ACI (5) or the AK protocol via Ethernet.

Product vision: Seamless application – from function design to fleet testing

Over the past few years, INCA-FLOW's customer base has continuously expanded. INCA-FLOW users report time savings and efficiency improvements of between 30 and 80 percent, as well as a significant improvement in the quality of calibration data and far greater reproducibility of the results in test drives. ETAS and IAV intend to continue their INCA-FLOW development partnership. Their goal is to establish INCA-FLOW throughout all the different phases and environments of powertrain system development (Fig. 5).

Future versions of INCA-FLOW will support the automated validation of vehicle systems in conjunction with drive recorders such as the ES720 module from ETAS (Fig. 6). In this case, INCA-FLOW procedures will run on drive recorders in test fleet vehicles without supervision and manual intervention. At the same time, INCA-FLOW data analysis methods can be used to directly analyze measured data online on the drive recorder. Among other things, this approach is suitable for the validation of on-board diagnostics (OBD) in fleet testing.

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