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dSPACE NEWS

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SystemDesk Simulates ECU Networks

Bentley - Virtual Test Drives with MotionDesk

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dSPACE NEWS

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Tel.: +49 52 51 16 38-0 · Fax: +49 52 51 6 65 29
dspace-news@dspace.de · info@dspace.com
support@dspace.de · www.dspace.com

Project Manager and Author: André Klein
Technical Authors: Alicia Alvin, Bettina Henking-Stuwe, Ralf Lieberwirth, Sonja Lillwitz, Julia Reinbach, Dr. Gerhard Reiß, Klaus Schreber
Editors and Translators: Robert Bevington, Stefanie Bock, Christine Smith
Layout: Beate Eckert, Tanja Raeisi, Sabine Stephan

4 *Valeo Systèmes Électriques, a member of the Valeo group, used dSPACE tools according to the standardized V-cycle to develop a reversible, belt-driven starter-alternator.*

10 *For calibration tasks such as vehicle dynamics functions, BMW is increasingly using highly dynamic test benches equipped with powerful dSPACE real-time hardware and software.*

Powertrain development seems to be a never-ending story. There's so much going on, even for just the engine alone: more variable valve control, new turbochargers and injection valves, closed-loop combustion pressure control, super-high-pressure common rail, gasoline direct injection, homogeneous charge compression ignition, several catalytic converter and diesel particulate filter technologies, variable compression, alternative fuels … the list goes on and on. Then there's all the work being done on transmissions, numerous forms of hybrid drive, and fuel cells – the technology of the future. Meanwhile, requirements for onboard diagnostics are becoming more demanding. And now CO_2 is the subject of heated debate. Personally, I'm not convinced that all the politically imposed targets are really useful. But even if they are, it's completely unnecessary for regulations to be different in Europe, Japan, China, USA, etc. Not only do different countries have different requirements regarding emissions, if the requirements do happen to be the same by chance, they're introduced on different dates.

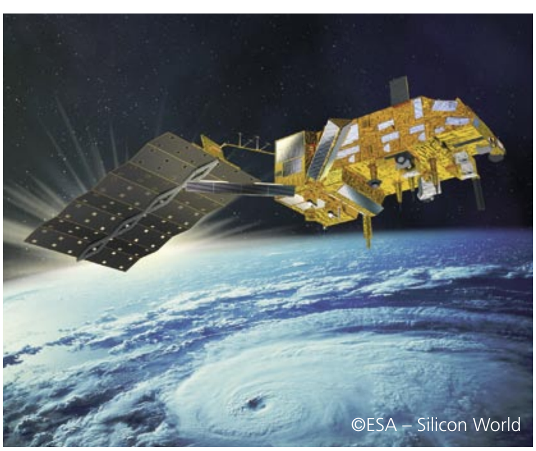
This is an enormous challenge for powertrain engineers at OEMs, suppliers, and engineering service providers. For dSPACE, it's good news. After all, it's no coincidence that so many of our automotive product sales are for the powertrain, with so many developments going on.

The debate on how to meet emission limits, and at the same time give customers the economical yet fun-to-drive vehicles they want, is in full swing, and I'm keeping a close eye on it. What particularly interests me is diesel, as I have driven nothing but diesel for many years. I did some really dynamic driving in my first diesel station wagons. If I drove more economically, I could do 1000 km on one tank. My current high-performance diesel can't do this. But it's even more fun to drive, with massive torque and propulsion. No, I don't drive the Audi R10, the first diesel to win the 24 Hours of Le Mans, with 1100 Nm torque and 650 HP.

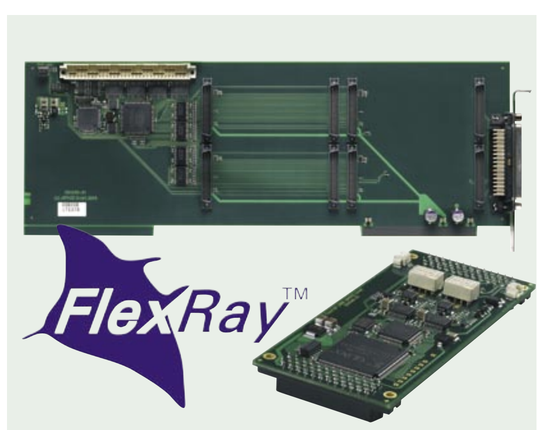
European OEMs are currently well on their way to making diesel cars popular in the USA. It'll be interesting to see how quickly they succeed. The challenge is not only psychological – diesel does not have a positive image in the USA – it's also technical. For example, particulate emission already has to be 4 times lower than the current Euro-4 standard in Europe. Nitrogen oxide values have to be 4 times lower than the Euro-5 standard, which was just passed and is not even in effect yet.

Hats off to everyone working to solve such problems and to make sure that the technology will still work even after years of aging under the most adverse conditions.

Dr. Herbert Hanselmann
President



14 *CSEM has developed an optical delay line control for the European weather satellite, the Meteorological Operational Satellite (or MetOp for short), using a dSPACE prototyping system.*



25 *dSPACE has extended its hardware for FlexRay applications, adding the DS4340 FlexRay Interface Module and the DS4505 FlexRay Interface Board to create a coordinated hardware package.*

Eco-Friendly Starter-Alternator

- Micro-hybrid concept developed with dSPACE aid
- Reduced fuel consumption and CO_2 emissions
- Engine's behavior simulated with dSPACE Simulator

Valeo Systèmes Électriques, a member of the Valeo group, used dSPACE tools according to the standardized V-cycle to develop a reversible, belt-driven starter-alternator. This innovative concept brings together the features of an alternator and a starter in one product to reduce fuel consumption and CO_2 emissions. During the development process, Valeo first descended the V-cycle using automatic code generation with TargetLink, then ascended the V-cycle using dSPACE tools combined with Valeo facilities and methodologies.

The StARS Micro-Hybrid Concept

Electrical energy in the vehicle is a key factor in meeting the requirements of motorists and the general public for more comfort, enhanced mobility and less pollution. Valeo's micro-hybrid concept combines the functions of a starter and an alternator in one unit: the starter-alternator StARS. The StARS system is made up of an electric machine, an associated control box, and a three-phase cable linking the two, all fitted under the hood.

The electric machine is reversible. It is a traditional alternator which is made to operate like an electric motor by controlling the phases. In alternator mode, part of the mechanical energy of the internal combustion engine is converted into electrical energy, which is stored in the battery and feeds the on-board power supply network. In starter mode, the electrical energy is taken from the battery to produce mechanical energy used to start the combustion engine. Valeo uses the system's capacity to stop and then restart the vehicle's engine immediately, silently, and in a transparent way for the driver. This technology therefore saves fuel and avoids pollution when the vehicle stops at a red light, in a traffic jam, or when making a delivery. The vehicle starts up again quietly and automatically as soon as a gear is engaged or, in automatic vehicles, when the foot is released from the brake; the system operates discreetly without disrupting the driver's normal driving habits. Consumers will benefit from up to ten percent fuel savings, zero emissions when the vehicle is at a standstill, and reduced noise levels.

▲ *The StARS micro-hybrid system: Electric machine, three-phase cable, and control box.*

Code Generation with TargetLink

The StARS system and the associated control box contain embedded software which can be divided into basic software, abstraction layer, and application components. The basic software consists of standard interfaces. The abstraction layer above it gives access to variables via get and set functions. It was generated by a proprietary tool. All application components were generated automatically by the TargetLink code generator and tested extensively with its test features.

Validation Bench with dSPACE Simulator

We integrated a dSPACE Simulator with a mechanical test bench to validate the StARS system. The complete validation bench consists of a dSPACE Simulator Full-Size, a control cabinet for the mechanical test bench including the load bench, and the mechanical test bench including an interface for the electric machine and the battery. The dSPACE hardware-in-the-loop simulator is equipped with a processor board which runs the environment model, a set of I/O boards and signal conditioning cards, a set of power supplies and switches, a fault insertion unit, and network resources (for example, CAN, LIN), etc. The mechanical test bench simulates the internal combustion engine as viewed from the StARS system. It contains an electric motor with its variable-speed controller. The loads connected to the bench may be simulated or real. The load bench used is in fact an electronic load used to dissipate energy. It simulates the current consumers in a vehicle, and contains a real battery and a set of power supplies. We have access to a single 12 V battery, or a 36 V battery. The battery can also be simulated if necessary.

▲ The validation bench based on dSPACE Simulator Full-Size.

Used Validation Software

A number of programs are required to operate the validation bench. Some are supplied by dSPACE, the others have been developed by our team. The following programs are used with the bench:

- MATLAB®/Simulink®/Stateflow® to design the environment model
- Real-Time Workshop® from The MathWorks combined with dSPACE's Real-Time Interface to generate, compile and load code into the test bench
- dSPACE's ControlDesk to control the validation bench
- dSPACE's AutomationDesk to automate the actions carried out under ControlDesk

Brilliant Support

The aim of the StARS validation process was to optimize the supply and management of the electricity, and to ensure that the engine starts and restarts quickly and quietly. Whether descending or ascending through the standardized V-cycle), dSPACE provided a solution to our requirements. In general, a standard solution from any one supplier never exactly meets the requirements of the customer. What we appreciate about dSPACE is that it allows us to add to their environment by using simple proprietary solutions and without having to do too much development. For validation, the service provided by dSPACE is not only hardware and software, but also intellectual, with the creation of a solution specific to our application.

Sébastien Roue
Functional validation manager
Valeo Systèmes Electriques
France

Dongfeng Automates Manual Transmission

- Innovative powertrain project at Dongfeng in China
- Development of a 12-speed automated mechanical transmission (AMT)
- Production code for automatic shift control with TargetLink

Vehicles with automated mechanical transmission (AMT) combine the comfort features of an automatic transmission with the cost advantages of a manual gearbox. Using a commercial truck with a 12-speed manual transmission as a basis, Dongfeng developed a new AMT system including a control unit for automatic gear shifting. The production code generator TargetLink was used to generate the control software and helped to reduce the development time.

The Dongfeng company (the Chinese name means east wind) is one of the five largest Chinese car manufacturers and the leading manufacturer of Chinese commercial motor vehicles. A research team at Dongfeng developed a new Automated Mechanical Transmission (AMT) based on the EQ4195 truck with a 12-speed manual transmission. The system consists of a 12-speed mechanical gearbox and an automatic shift control system (ASCS). The ASCS includes several sensors and actuators, and a transmission control unit (TCU). The actuators are powered by air supply. The TCU takes input signals such as velocity, brake pedal position, gas pedal position, and engine speed into account to control the actuators. The input signals are delivered by directly connected sensors or derived from the vehicle CAN.

▲ *The automatic shift control system was developed for the EQ4195 truck from Dongfeng.*

Features of the Dongfeng AMT System

- Obvious reduction of fuel consumption and emission
- Comfort improvement due to automated shift
- No clutch pedal
- Selectable modes: economy, power, mountain
- Failure detection and the clutch & transmission protection by the system software
- Cost, weight and packaging optimized design
- Different driving styles possible

Tools and Development Cycle

The function model developed with Simulink® was first tested in the truck with a dSPACE MicroAutoBox.

> *"By implementing the automatic shift control system, we succeeded in considerably reducing fuel consumption and improving powertrain efficiency."*
> ***Hongfei Ni, Dongfeng***

The developed functions were already optimized and adapted to the mechatronic system during the prototyping phase. To implement the model on the TCU equipped with a Freescale MC9S12DT128B microcontroller, fixed-point object code had to be generated. The automatic scaling features of TargetLink were of great help in fine-tuning the fixed-point code. Automatic scaling was a huge time saver as it took away the tedious and error-prone task of manually scaling each variable and each operation in the software. The precision of the scaled code was easily judged by comparing model-in-the-loop

(MIL) with software-in-the-loop (SIL) simulations; errors like overflows were detected that way. The final object code was generated using the CodeWarrior compiler and merged with custom code.

Advantages of Production Code Generation with TargetLink

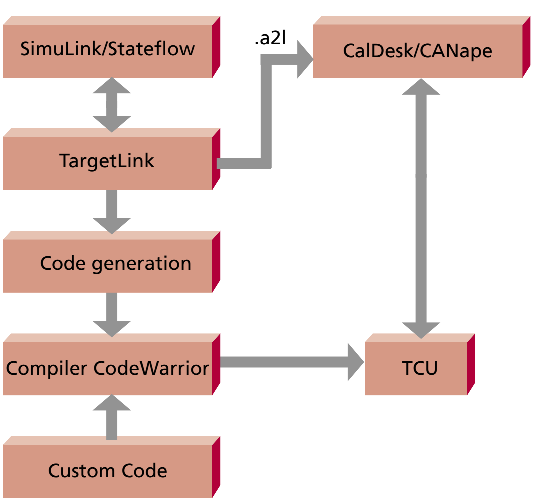
When the production code generator TargetLink is used, the definition of the module function is clearer, and implementing and validating the arithmetics is more convenient and takes less time. The model data is completely managed in TargetLink. In addition, the A2L file which is

> *"TargetLink greatly improved the efficiency and quality of the control software for our automated mechanical transmission."*
> ***Hongfei Ni, Dongfeng***

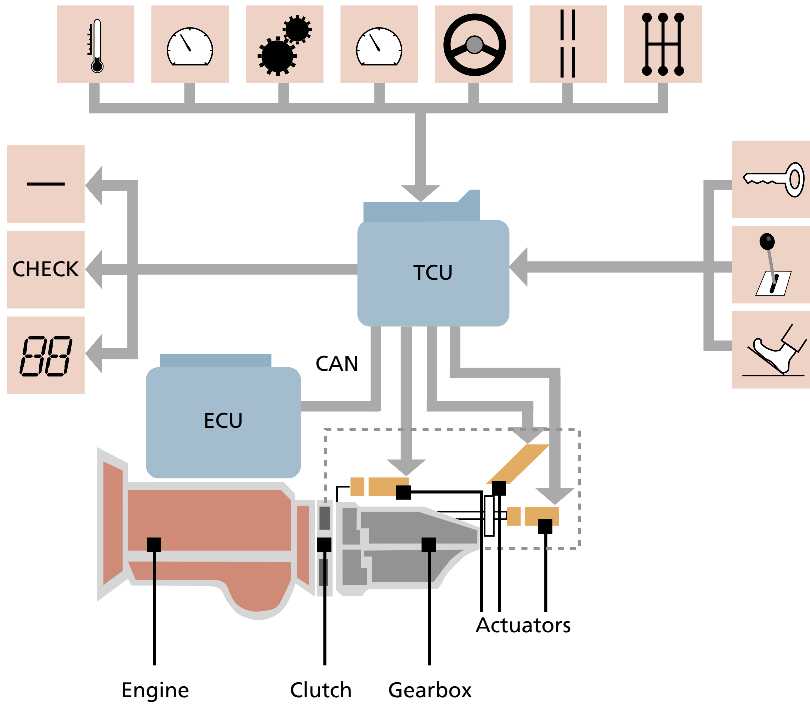
required by the calibration software also can be generated with TargetLink. Overall, the efficiency and quality of development can be greatly improved.

Verification and Validation of Controller Functions

The TCU was then tested in a hardware-in-the-loop test environment based on dSPACE Simulator. Before, too much time and work would be required for the TCU test with manual methods. We would have to do validation tests on actual vehicles. Now, some tests which cannot be finished in a normal environment can be done by using the simulator. Moreover, with the automated test runs, test can be performed more systematically, resulting in greater test efficiency.



▲ *The AMT control system development cycle.*



▲ *The components and signals of ASCS.*

Results

By implementing this automatic shift control system, the Dongfeng research team has succeeded in considerably reducing fuel consumption and improving powertrain efficiency. For example, the driver has much less work to do than with the predecessor systems.
The tool chain supplied by dSPACE, with its largely automated procedures, makes the process to a large extent seamless and ensures very good reproducibility. This considerably reduced the time used to develop the TCU and also increased the quality of the code that was produced, and greatly facilitates the development and implementation of control systems.

Outlook

The system is currently undergoing second-cycle development. Meanwhile, improvements are also being made to the development process. A real-time operating system (such as OSEK), well supported by special blocks in TargetLink, is used in the new development, and multi-rate implementation will be realized by using TargetLinks multi-rate features.

Hongfei Ni
Dongfeng Research and Development
Wuhan, China

Networked Tests at ZF

- ZF Friedrichshafen boosts efficiency by seamless tool landscape
- AutomationDesk, ControlDesk and MotionDesk for ECU tests
- Test automation is a major element in HIL testing

With increased networking of vehicle electronics, optimized validation methods and processes are vital. One important quality assurance activity is to run defined, standardized tests on electronic control units (ECUs) at various stages of development. Hardware-in-the-loop (HIL) tests are a major part of this process. They range from tests on single ECUs, to the validation of entire system areas, and right through to representations of whole vehicles. The seamless use of dSPACE hardware and software throughout the process provides a highly efficient test environment.

ZF Friedrichshafen AG is a system supplier that develops and produces electronically controlled drivetrain, steering, and vehicle systems. HIL testing is an important element in our development process, enabling us to detect and remedy errors in the laboratory at an early stage, and also to boost testing efficiency by means of reusable test cases.

dSPACE Technology for Rapid Prototyping and HIL Test Stations

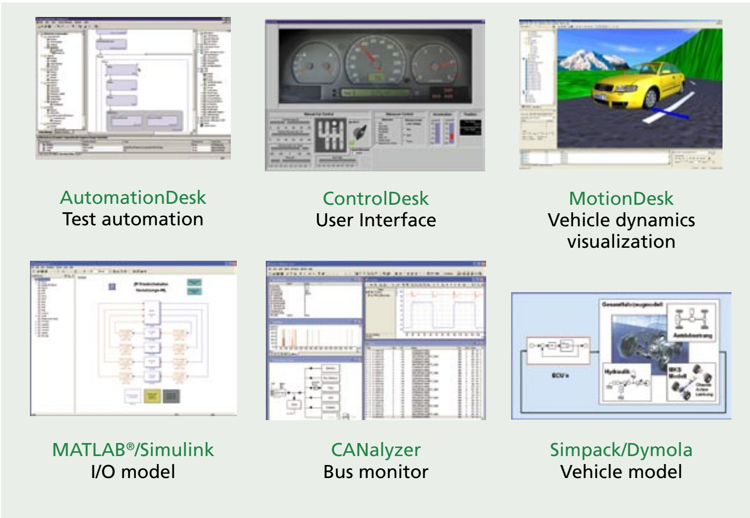
ZF Friedrichshafen AG offers a wide range of drivetrain and chassis systems. The ways in which we use dSPACE systems are correspondingly varied, with regard to both rapid prototyping and hardware-in-the-loop technology. For HIL tests especially, we frequently employ dSPACE test stations equipped with the appropriate tool chains, for example, ControlDesk, AutomationDesk, and MotionDesk. We use the dSPACE technology for tests on single ECUs, called component testing, for network testing of ECUs, and for virtual test drives using vehicle models. ZF Friedrichshafen has constructed a powerful network test station for testing the entire aggregate of drivetrain and chassis controls. The test station includes such items as all-wheel drive with control systems for the automatic, distributor, and axle transmission; for slip controller systems; and for the active chassis.

Network Testing

Bringing individual components together in the vehicle involves an enormous amount of work. Frequently, the first time that components interact is after installation in the laboratory vehicle. Much less time is needed to put the vehicle into operation if component interaction is tested beforehand. We integrate the target vehicle's most important ECUs and investigate how they behave in a network. The focus is on their reciprocal effects and ECU-independent functionalities, for example:

- The ECU network's reaction to faults in the vehicle electrical system
- The robustness of the system network when individual components malfunction
- Effects due to different features in different vehicle variants
- Evaluating the controllers with regard to vehicle dynamics

▼ *HIL simulators for testing networked ECUs.*



▲ *Part of the tool landscape in the network test station at ZF Friedrichshafen.*

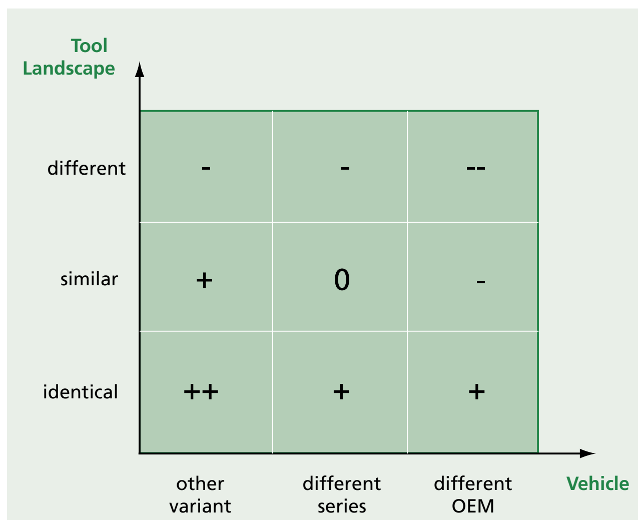
The mechanical systems that the ECUs are installed in are simulated in real time. A dSPACE multiprocessor system with associated I/O calculates the vehicle model and the sensor signal emulation for the ECUs. We use MotionDesk, the 3-D animation software, to visualize the virtual test drives realistically in 3-D scenes.

Test Automation

Complex systems require a large number of tests, but the actual test sequences are continually repeated. Test automation is extremely helpful here. To keep the costs as low as possible, we create test case libraries. These hold collections of test specifications and associated test cases, which are used in various projects. Thus, we do not have to program diagnostic tests from scratch for every product, but can use the ones we have for several ECUs. dSPACE's test and experiment software, AutomationDesk, enables us to run test sequences in a reproducible manner and with reproducible quality, avoiding the deviations that arise with manual test execution. Moreover, automatic tests can run overnight and on weekends, so we have a minimum of routine tasks to do ourselves. AutomationDesk generates test reports, and all we have to do is look at the results and interpret them.

Reusability Potential of Test Cases

ZF Friedrichshafen has more than 20 years of experience in using hardware-in-the-loop technology. We have accumulated a wide range of knowledge on test methods and test cases during this period. One of our major know-how resources is a comprehensive test library implemented by means of AutomationDesk. The test library ensures optimum test reusability. It is divided into two parts. The first is the test module library, which contains elementary test modules that can be reused in several test cases. The second part is the test case library; this holds the complex, ECU- and vehicle-specific test cases, which are basically built up using the test modules. Our customers benefit from this test library, which we naturally make use of in joint projects.



▲ *The cost/benefit ratio for reusability potential according to tool landscape and target vehicle.*

Dr. rer. nat. Horst Krimmel
Dipl.-Ing. Oliver Maschmann
Corporate Research and Development - Electronics Chassis (TE-F)
ZF Friedrichshafen AG
Germany

Glossary

Laboratory vehicle –
Vehicle test bench for testing interaction between ECUs.

Test case –
Defined test sequence with specifications for specific functions.

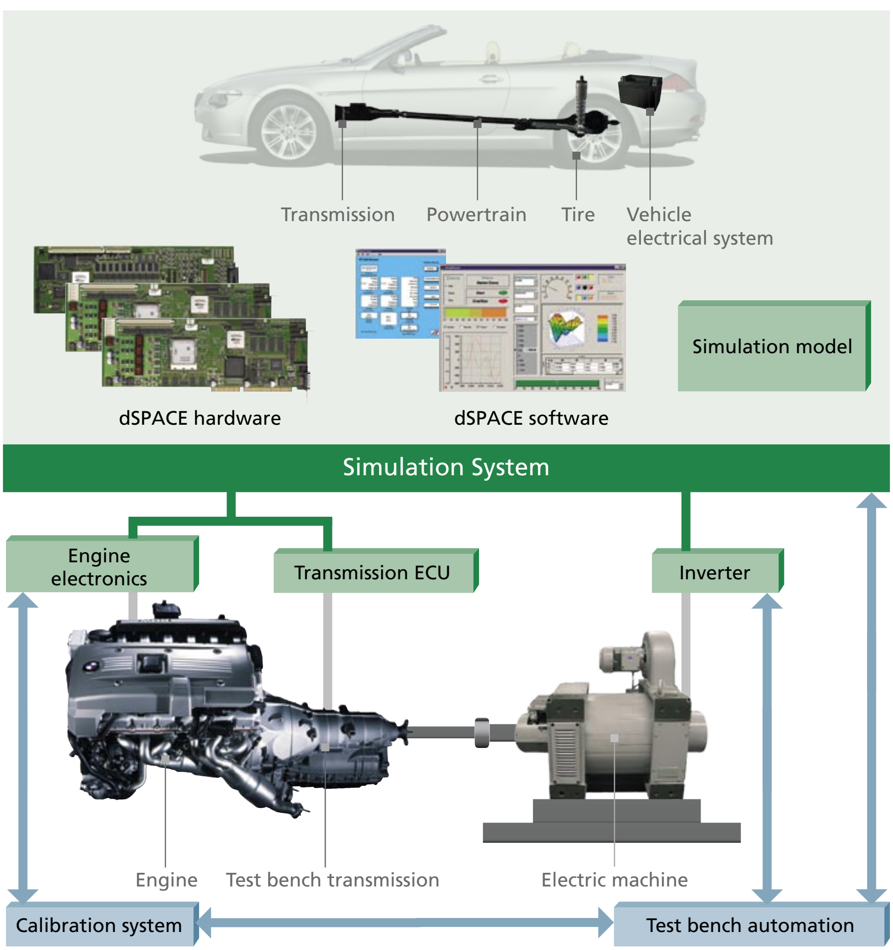
BMW – Highly Dynamic Test Benches

- **DS1006 Processor Boards at 3 GHz for real-time calculation**
- **The next generation of powerful test benches**
- **Flexible calibration options**

Performing calibration tasks on a real test vehicle fleet can be time-intensive and expensive. BMW is able to cut its development times and costs considerably by shifting some of its calibration work to test benches. This requires detailed simulation of real vehicle behavior – for example, in calibrating vehicle dynamics functions on an engine test bench. BMW's solution is highly dynamic engine test benches that can precisely mimic longitudinal vehicle dynamics in the relevant frequency range. The simulation systems of the test benches include powerful dSPACE real-time hardware and software.

The Test Benches of the Future

These highly dynamic engine test benches are far more powerful than standard test benches, and by using them to simulate longitudinal vehicle dynamics, BMW is able to cut the number of test vehicles needed despite a growing volume of calibration work. The only real component installed on the highly dynamic test bench is the engine, so all the other components have to be represented in detail by the simulation system. This is not possible without powerful hardware and software. BMW is using modular dSPACE systems for real-time calculation, each equipped with two DS1006 Processor Boards running at 3 GHz, DS2211 HIL I/O Boards, and others. Added to these are PROFIBUS interfaces, CAN interfaces, the Real-Time Interface, and the test and experiment software ControlDesk.



◀ *dSPACE real-time hardware and software are at the core of the simulation system in BMW's highly dynamic engine test bench.*

The Test Bench at a Glance

Each of BMW's highly dynamic test benches has one real engine and a test bench transmission installed, the two being connected via a shaft with an electric machine. The simulation system, consisting of dSPACE real-time hardware and software, plus an extensive engine- and vehicle-specific simulation model, accesses the electric machine control directly. The clutch, the transmission ratios, and the efficiencies are mapped in the simulation system via a transmission model. Further model components are tire slip simulation and restbus simulation, using original vehicle data. The entire simulation system is modular, so it can adapt to a wide range of calibration tasks. A simulation drive is also integrated into the test bench to represent actions such as starting and stopping the engine, driving off, constant speed; stopping, accelerating, gear shifts and coupling, and load changes. The system can handle any combination of maneuvers, and also dynamic drive cycles. Even though the model is less complex than a real vehicle because of real-time requirements, BMW achieves excellent agreement between test bench measurements and actual vehicle measurements.

◀ Highly dynamic test benches were also used for calibration in developing the new BMW 3 Series.

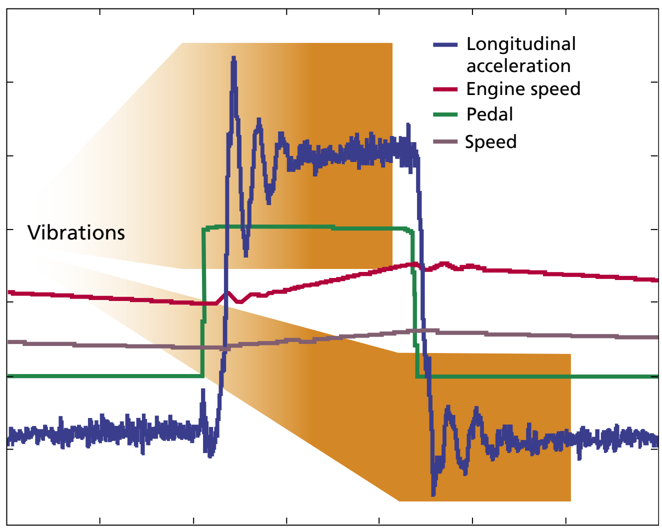
Varied Application Fields

BMW's highly dynamic engine test benches have been in productive use for some time now.

- Load change functions can be calibrated by mapping longitudinal vehicle dynamics. In the vehicle, the effects on driving behavior can be felt immediately; on the test bench, the calibration engineer uses the measured data to evaluate changes in driving behavior.
- Optimized start-up functions in the engine ECU support the driver in driving off, with low or no accelerator pedal angles.
- Switching processes in the intake system on the engine are optimized so well that the driver can scarcely perceive them during constant speed or acceleration.
- BMW compares different ECU data sets to assess the quality of the calibration.

The Way Forward

Being able to turn standard test benches into highly dynamic test benches makes for a fast response to increased requirements. BMW now aims to introduce calibration tasks on highly dynamic engine test benches even earlier in the process. Calibration will then be possible before a real test vehicle even exists. The powerful dSPACE hardware and



▲ Jerks in longitudinal vehicle acceleration after load changes: The test bench helps to find the optimum settings.

software, in this case additionally equipped with LIN and FlexRay interfaces, will be at the core of the simulation system.

Dr.-Ing. Franz Froschhammer
Dept. Methodology, Test Beds
BMW Group
Germany

Source: "Hochdynamische Prüfstände: ein Werkzeug für die Instationärapplikation", BMW Group, ATZ/MTZ-Konferenz Motor, Wiesbaden, November 2006

Active Noise Reduction

- **Developing active noise reduction for turboprop airplanes**
- **Department of Mechatronics relies on dSPACE ACE Kits in research and teaching**
- **Parallel DS1005 PPC Boards provide the necessary computing power**

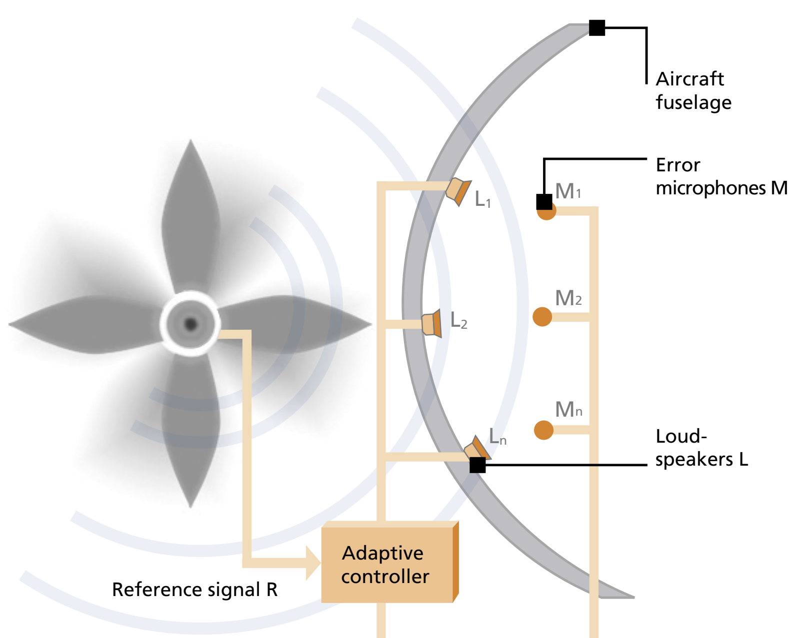
The Department of Mechatronics at Helmut Schmidt University (HSU) / University of the Federal Armed Forces Hamburg, Germany, is developing systems for active noise reduction. Research is currently focusing on active systems for turboprop airplanes, whose powerful engines cause high sound pressure inside the plane, experienced by passengers and crew as loud noise. To develop noise reduction systems, the department is using several dSPACE ACE Kits with the DS1103 PPC Controller Board in both research and teaching, and a multiprocessor systems based on two DS1005 PPC Boards for particularly high performance requirements.

The passive noise insulation currently in widespread use employs heavy noise-damping material in the airplane's outer skin. Active noise control (ANC) has the decisive advantage over this of saving weight. No heavy material is used; instead, a counterwave cancels out the disturbance sound wave.

Active Noise Control

An ANC system basically consists of reference sensors (R), loudspeakers (L), error microphones (M) and a digital controller. Reference sensors record the reference signal, which depends on the engine speed and corresponds to the primary sound field. The controller processes this reference signal by means of adaptive filters, and returns it via the loudspeaker as a 180° phase-shifted counterwave of the same amplitude (secondary sound wave), so that the two sound waves cancel each other out. However, the counterwave is affected by various factors such as variations in air pressure and temperature. The error microphone returns these variations or "errors" to the controller as disturbance variables, and the controller recalculates the secondary sound wave. The controller has to combine robustness and adaptivity in order to react to the wide variety of effects working on the sound field. Our research work is currently concentrating on developing these control strategies, and on skillful placement of loudspeakers and error microphones.

> *"The dSPACE multiprocessor system gives us a way of developing fast controllers at a high abstraction level."*
> ***Prof. Dr. Delf Sachau***
> ***Helmut-Schmidt-University / University of the Federal Armed Forces Hamburg***



▼ *The basic structure of the control system for active noise control (ANC).*

Local and Global Noise Reduction

We already ran several projects implementing experimental setups for local noise reduction, for example, as part of the aviation research program of the City of Hamburg and in a program sponsored by the Deutsche Bundesstiftung Umwelt (German Federal Environment Foundation). These projects were concerned with noise reduction in a restricted space of around one cubic meter. A current focus of our scientific work is on designing an ANC system for global noise reduction. Depending on the application, global noise reduction means preventing sound propagation to the outside or quieting a very large space, such as the entire interior of an airplane. However, global noise reduction requires a considerably greater number

▲ *Experimental setup of a loudspeaker-error microphone system for active noise reduction.*

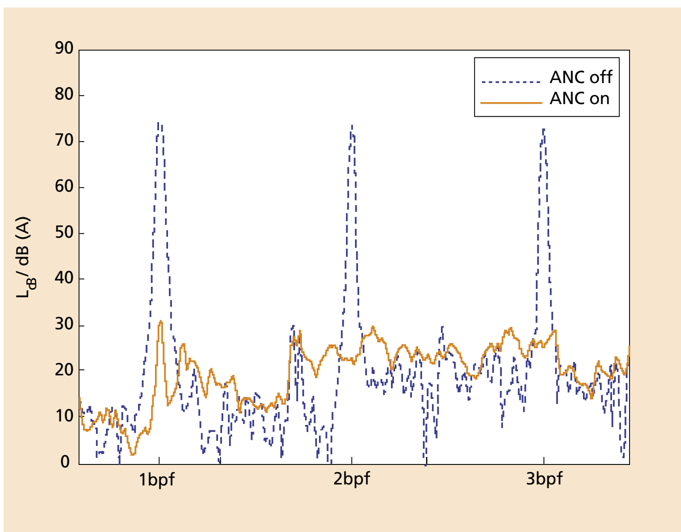
of error microphones and loudspeakers than local noise reduction. The photo shows what an experimental concept for global active noise reduction, with relatively few error microphones and loudspeakers, could look like. By means of the loudspeaker-error microphone array, the ANC system prevents the noise from passing from the first to the second laboratory room via a sound transmission opening. No noise is perceived in the second room. As an example, the graphic shows the controller success at one of the error microphones. The frequency spectrum comprises three dominant frequencies: 1st bpf, 2nd bpf, 3rd bpf. "bpf" is the blade passing frequency, i.e., the frequency of the disturbance noise emanating from the rotor blades. The 1st bpf is the frequency at which the rotor blade tips pass the plane's fuselage.
The 2nd and 3rd bpf's are both multiples of the first bpf. It can clearly be seen that the 1st, 2nd, and 3rd bpf's have almost completely disappeared from the frequency spectrum when the ANC system is switched on.

"With the modular hardware concept from dSPACE, we can tap into computing performance with virtually unrestricted scalability, and use it to develop ANC systems that can be executed in real time despite high sampling rates."

Dipl.-Ing. Kay Kochan
Helmut-Schmidt-University / University of the Federal Armed Forces Hamburg

Controller Development with the Multiprocessor System

The controller development for this ANC system is performed in the graphical development environment of MATLAB®/Simulink®. In accordance with the model-based approach to controller development, this especially shortens the time between the idea for the controller and its implementation on the processor. At the same time, this procedure guarantees transparent teamwork on controller development, even where students are involved in current research. Above all, however, errors in the algorithm can be detected very early on by means of simulation. As the number of loudspeakers and error microphones rises rapidly, so too do the requirements for computing power. dSPACE's modular hardware concept provides the necessary performance by allowing processors to run in parallel. At the moment we are implementing controllers with up to 40 error microphones, 20 loudspeakers, and one reference sensor. For error-free calculation of the secondary sound signals, we implemented 60 adaptive filters and 2400 secondary plant models in the controller. This would not have been possible without a multiprocessor system consisting of two parallel DS1005 PPC Boards and various I/O boards. With the DS1005 multiprocessor system, we are able to implement active noise reduction projects that are extremely complex in terms of control technology.



▲ *With the ANC switched on, the three blade passing frequencies (bpf) manifest noise reduction by 45 dB, 51 dB, and 47 dB to the level of background noise.*

Captain Dipl.-Ing. Kay Kochan
Prof. Dr. Delf Sachau
Helmut-Schmidt University / University of the Federal Armed Forces Hamburg
Germany

Europe's New Weather Satellite

- Satellite for weather and climate research
- Mirror control developed with dSPACE prototyping system
- Long-term weather forecasts, extensive data for climate research

The European weather satellite MetOp (Meteorological Operational Satellite) was launched from Baikonur in Kasakhstan on October 19, 2006. At the heart of the satellite is the Infrared Atmospheric Sounding Interferometer (IASI), an instrument for measuring the distribution of temperature and humidity, and the chemical composition of the atmosphere. The high quality of the measurements is largely determined by an optical delay line control developed by Swiss company Centre Suisse d'Electronique et de Microtechnique (CSEM), using a dSPACE prototyping system.

▶ The weather (such as the storm front shown here) takes place at altitudes of up to 20 km. The MetOp satellite collects weather data from various altitudes, which is important for more accurate weather forecasts.

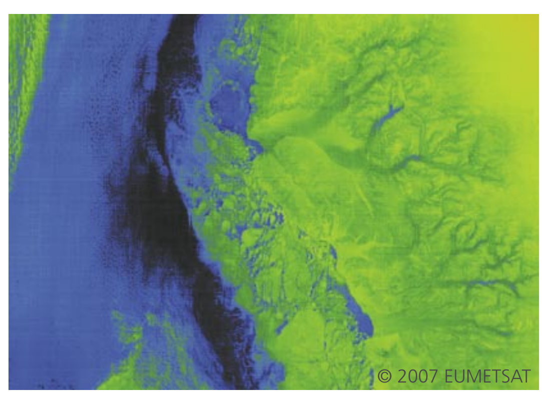
The Atmosphere Is Not Flat

In the satellite picture shown in television weather forecasts, the atmosphere appears flat. In actual fact, the weather occurs in an atmospheric layer 20 km thick, and varies considerably according to altitude. This is where the MetOp satellite comes in: orbiting low at an altitude of 820 km, in contrast to the high-flying geostationary satellites providing current meteorological images, it studies the atmosphere in layers and gives meteorologists a three-dimensional image of the weather. Moreover, it passes over the north and south poles. Its low polar orbit gives it a detailed view of the oceans and the polar regions, which are thought to be the Earth's "weather kitchen" but are not sufficiently covered by other satellites and weather buoys.

The Weather's Fingerprint

The three-dimensional weather images are produced from measurements made by the Infrared Atmospheric Sounding Interferometer (IASI). The IASI makes use of interference, i.e., the overlapping of light waves – the same thing that gives a film of oil on a puddle its rainbow-colored sheen. This is caused by interference between light waves reflected at the top and bottom surfaces of the oil film, and the film must have just the right thickness. In the IASI, it is the distance between the mirrors that must be right, and because one of the mirrors is movable, thus forming an optical delay line, the distance is constantly

> *"With the dSPACE Prototyping System we could easily adjust the controller for the scanning mirror of the meteorological interferometer on the MetOp weather satellite."*
> ***Emmanuel Onillon, CSEM***



▲ The western coast of Greenland as seen by MetOp. Its infrared images provide data on the distribution of temperature and humidity.

changing. Precise, periodic mirror movements are vital – it is these that cause an interference pattern in the detector, and this interference pattern is the atmosphere's "fingerprint". CSEM developed the control system for the mirror using a dSPACE prototyping system. Apart from precision, another essential objective was reliability – once in orbit, the satellite cannot be repaired.

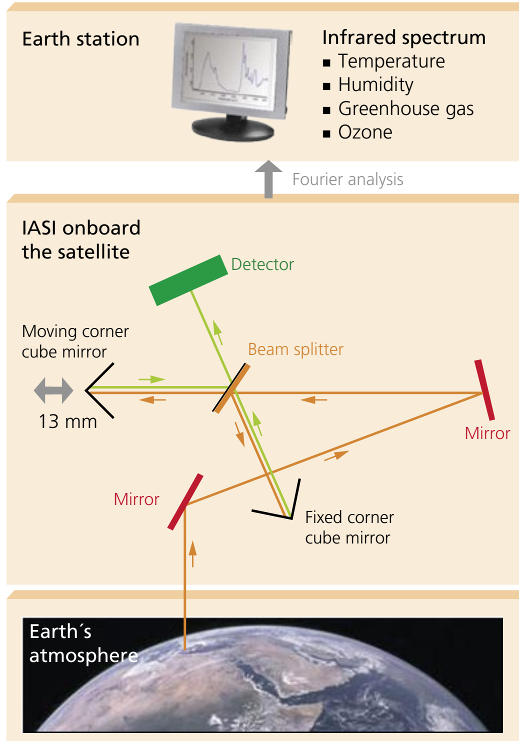
Regular as Clockwork for 7 Years

The mirror must move 13 mm backward and forward at a constant speed of 132 mm/s, and continue to do so for up to 7 years – the useful life planned for the satellite. This can add up to 400 million motion cycles, during which the mirror must never get out of sync. In the development setup, the control system (based on the DS1005) captures the position of the movable mirror at a sampling rate of 2 kHz via an optical encoder and calculates the optimum control input from this. The control system for the mirror motion is based on a PID controller and is self-adaptive, repeatedly optimizing the control algorithm to minimize the deviations between the ideal and the actual mirror positions. After it was finalized, the control was successfully validated in fixed-point mode. To rule out optical error, we used what are called corner cube mirrors, which always reflect back the incident light precisely, even if slightly tipped. This principle is well known in everyday life, for example, in rear reflectors on bicycles. Nevertheless, the straighten of motion is critical (less than 1 µm deviation from a straight line over the full scan range).

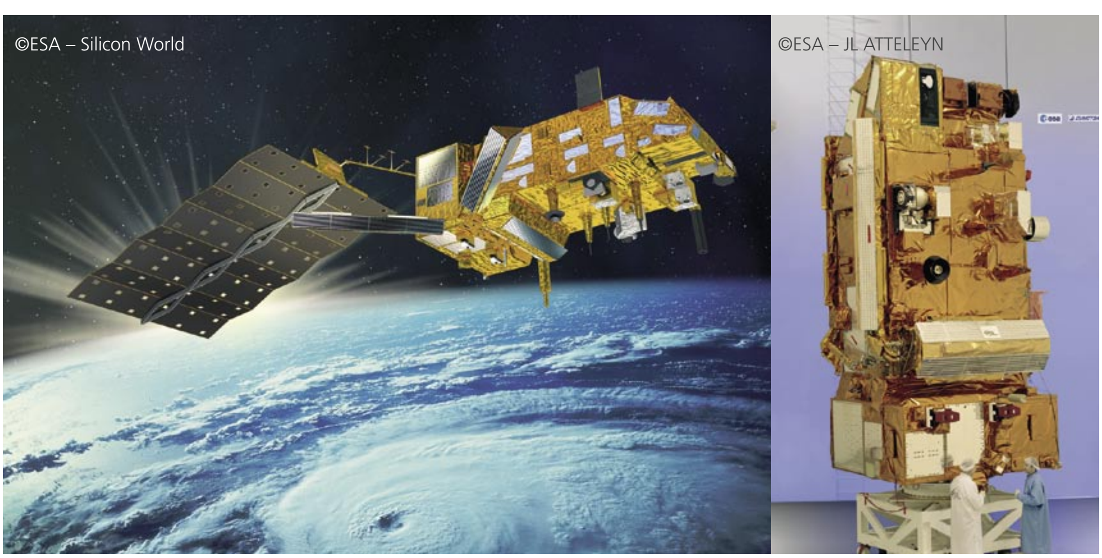
Long-Term Weather Forecasts

The MetOp satellite is a giant step forward for our knowledge of the Earth's weather and climate. Meteorologists can use the data it collects to predict the weather more accurately, and also to refine existing climate models – helping them to gain a better understanding of ongoing climate change, for example. Long-term weather forecasts have invaluable advantages: advance warning benefits both people and nature, transportation can be organized better, and the human and material resources needed in weather-dependent industries are easier to plan (construction, tourism, agriculture, power, etc.)

Emmanuel Onillon
CSEM
Switzerland



◀ *The Infrared Atmospheric Sounding Interferometer. The periodic motion of a corner cube mirror produces a "fingerprint" of the weather in the detector. Precise mirror control is vital; a dSPACE prototyping system was used to develop it.*



◀ *The MetOp satellite orbits the Earth over the north and south poles at an altitude of 820 km. Its Infrared Atmospheric Sounding Interferometer (IASI) scans the atmosphere constantly during orbit. Small picture: MetOp in the assembly shop.*

Flexible Hydraulic Controls

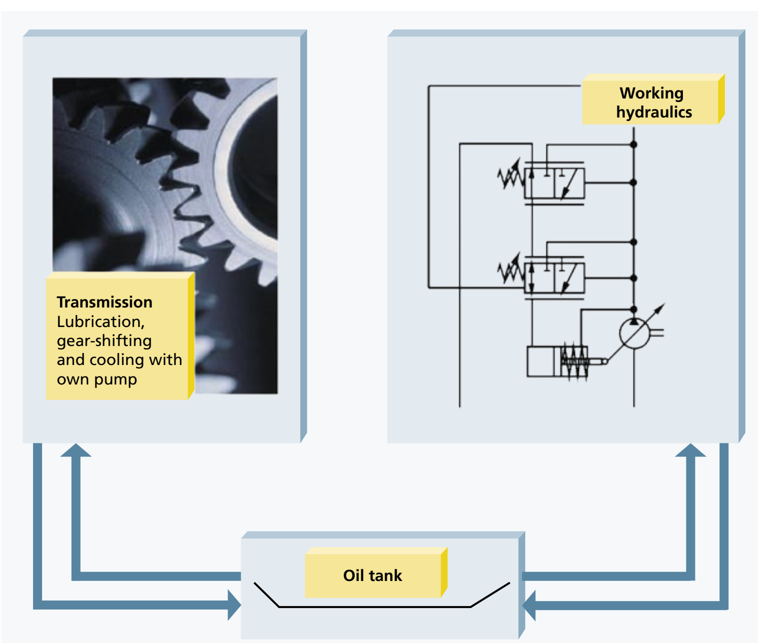
- **Air in Hydraulic Oil: Research topic at the Technische Universität Braunschweig**
- **Extensive measurement data capture combined with dynamic control tasks**
- **DS1103 PPC Controller Board as universal measurement technology hardware**

The Institute of Agricultural Machinery Sciences and Fluid Power at the Technische Universität Braunschweig, Germany has installed the DS1103 PPC Controller Board on several test benches used in research and teaching. An experimental hydraulic test bench is currently being used for research into "Air in Hydraulic Oil". Control models based on MATLAB®/Simulink® are being programmed, compiled, and with the aid of the ControlDesk experiment software, executed and monitored.

One major research area at the Institute of Agricultural Machinery Sciences and Fluid Power is concerned with the subject of "Air in Hydraulic Oil". We already carried out several research and development projects on "Foaming Behavior of Mineral Oils" for Volkswagen AG and for the fluid power division of the Verband Deutscher Maschinen- und Anlagenbau (VDMA, German Engineering Federation).

Transmission and Hydraulics Share Oil Resources

Many tractors have a single oil resource that is shared by the transmission and the hydraulics, so the institute is investigating whether shared use of oil by the two subsystems increases the problems caused by dispersion and surface foam, both due to free air in the mineral oil.



▲ *Mobile working machines like tractors often have a shared oil resource for transmission and working hydraulics.*

The Effect of Air in Hydraulic Oil

The oil is used for the hydraulics, transmission lubrication, and cooling. If air penetrates the oil circulation system, it causes a series of operating problems throughout the entire system. These include efficiency losses in energy utilization, malfunctions such as gear-changing problems, increased noise, and a shorter useful life for the oil. Additional air is pushed into the hydraulic oil by intermeshing gearwheels, for example, and then sucked in via the hydraulic pumps. The oil-air mix can get into the hydraulic circulation system by this route, and then cause the above problems as an air-in-oil dispersion. In the transmission sump (between the gearwheels and the oil collection points), dispersion can cause surface foaming, which in extreme cases can lead to oil losses due to oil foaming over.

Transmission and Hydraulics in an Experimental Setup

As part of the research on "Air in Hydraulic Oil" carried out at the institute, we set up a state-of-the-art experimental bench. This consists of the transmission of a standard tractor, a complete working hydraulic system, a load unit with hydraulic pump, and a load cylinder that runs via a second hydraulic cycle. The transmission gears and the hydraulics share the same oil resource, with the transmission serving as the tank for the hydraulic system. We equipped the transmission and the working hydraulics with sensors and actuators that are controlled via the various output modules of the dSPACE hardware. Actions such as gear shifts, which in a real tractor would be performed by a tractor ECU, were implemented by means of

◀ *The stationary test bench: The research team analyzes the effect of air in a working hydraulic system in a mobile working machine. From the left: Björn Grösbrink, Julia Leichnitz, Thomas Fedde.*

a dSPACE prototyping system based on the DS1103 PPC Controller Board. Thus, we can easily control different gear shifts from the host computer. The signals generated in the computer are transferred to electric magnets which switch various gear valves. We implemented the gear shifts under safe operating conditions using a logic circuit that was mapped in MATLAB®/Simulink® and that includes user prompts.

Measuring Dynamic Movements of a Hydraulic Cylinder

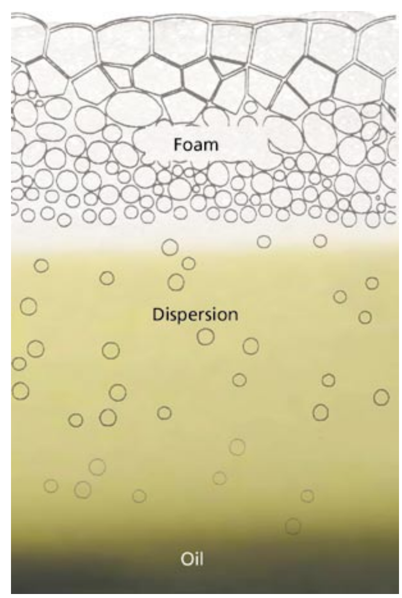
We established a defined, increased air content in the hydraulic oil for our experiments, and then measured the dynamics of the working hydraulics with the aerated oil. The load states of a real tractor working with a hydraulic cylinder (load equivalent from 0 to 6 tonnes) are mimicked by targeted loading of the differential cylinder,

> ***"We use dSPACE systems for controlling our experimental hydraulic test benches at the institute, because they allow numerous sensor and actuator signals, and CAN bus messages, to be processed simply and flexibly."***
> ***Dipl.-Ing. Julia Leichnitz, TU Braunschweig***

and the changes due to the increased free air content are analyzed. To define the effects of the air in the system, we installed more than 30 different sensors and recorded numerous analog signals, frequencies, and CAN bus messages at a high sampling rate. All the components from different manufacturers interacted smoothly, for example, the control of the frequency converter producing the input values for the electric motor that drives the hydraulic pumps; the control inputs for the tractor's CAN-controlled mobile hydraulic valves and the switching signals for the black-and-white valves (simple solenoid-controlled valves that are either open or closed and do not allow any position in between) for electrohydraulic gear-shifting, and the control inputs for the highly dynamic servovalves that provide fast load changes via the load hydraulics cylinder.

The Next Research Stage

The results of the experiments show that as expected, an increased quantity of free air in the system has a considerable effect on how the working hydraulics operate. Pressure losses and operating states with strong pressure fluctuations occur, as well as a high noise level. In the next stage of research, we will be looking at the material properties of the hydraulic oil to help us interpret the effects we have observed and evaluate the effect of free air in the system in greater detail.



▲ *Free air in hydraulic oil takes the form of air-in-oil dispersion or surface foaming. This can cause operational problems in the working hydraulics and the transmission.*

Dipl.-Ing. Julia Leichnitz
Institute of Agricultural Machinery Sciences and Fluid Power
Technische Universität Braunschweig
Germany

Bentley – Simulation for Luxury Vehicles

- Innovations for Bentley's new Continental GTC
- Bentley relies on dSPACE HIL solutions
- Driver-in-the-loop simulation with MotionDesk

For developing and testing the new Continental GTC, Bentley Motor Cars Ltd. relies on hardware-in-the-loop (HIL) systems from dSPACE. By using a simulated vehicle, Bentley can evaluate and validate all the electronic systems dynamically prior to eventual signoff at the test track. For example, a new approach for the GTC Tyre Pressure Monitoring system (TPM) required a HIL solution that provided a quick, low-cost and fault-free dynamic test capability to get new features on the road faster.

The Continental GT Convertible is the latest member of the Bentley Continental family. As a manufacturer of luxury vehicles, our development and production facilities are set up for low-volume but high-value cars. Although such niche cars have correspondingly limited development budgets, the customers of luxury vehicles expect reliability and quality standards to exceed those of more mass-produced vehicles. That is why we at Bentley rely on extensive HIL tests to achieve quality and reliability for the customer.

▲ *MotionDesk visualized driving maneuvers during driver-in-the-loop tests.*

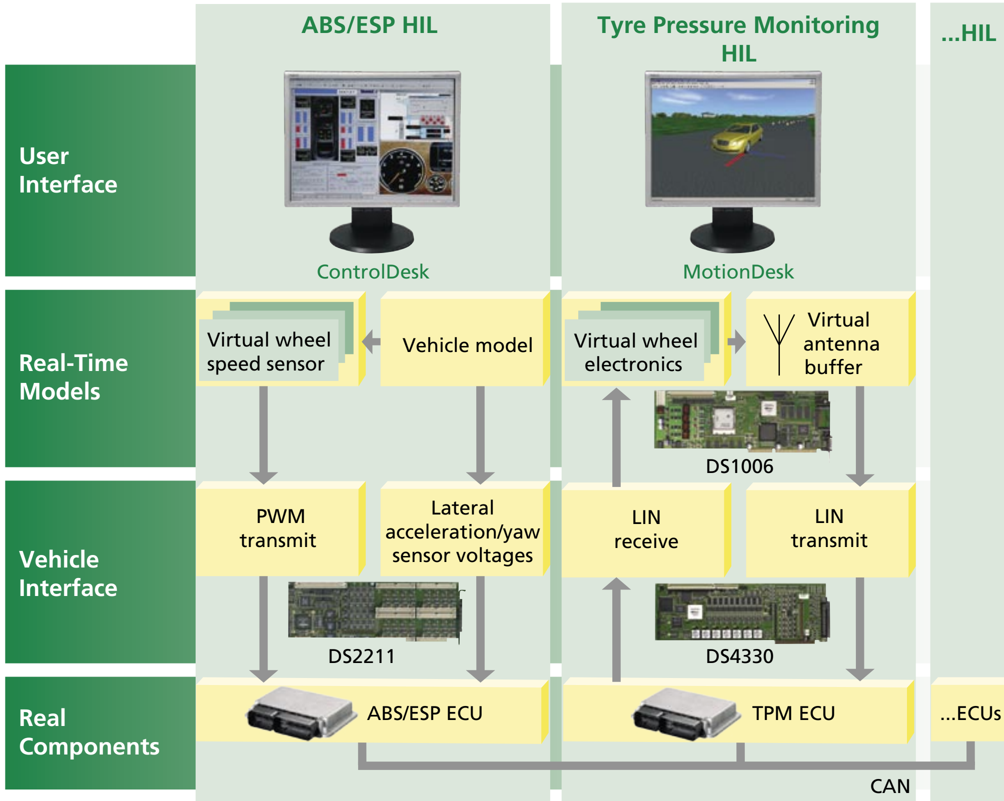
Testing Focus

As the development of comprehensive new models is prohibitively expensive, model-year updates are necessary to incorporate the latest technologies. These additional features require an integrated test approach, which means we focus the testing and test tools where the most significant deviations have been made. For example we have introduced additional functionality in safety-critical systems such as the Tyre Pressure Monitoring (TPM) system and electronic parking brake. Bentleys have no speed limiter fitted and can easily go over 300 km/h. With our HIL system we are able to perform the majority of these potentially dangerous tests within the laboratory, requiring vehicle tests on the road only for final signoff when we are sure the systems are robust and fully functioning.

▼ *The Continental GTC by Bentley.*

HIL in Action

The TPM system was recently improved to use a Local Interconnect Network (LIN) solution comprising LIN-based trigger units in each wheel-arch and a centralized LIN antenna to receive the responses from the in-wheel electronic sensor units. This solution allowed us to implement an HIL interface using the DS4330 LIN Interface Board for connection with real LIN components. The added customer-visible functionality included not only tyre pressure/temperature information but also a matrix of speed/pressure warnings to warn the driver if the tyres were not suitably prepared for very high-speed motoring. With the HIL solution in place, the test engineer can now 'drive' the simulated vehicle to the desired speed and then perform a variety of tests in ControlDesk from dSPACE. These include verifying the threshold performance at accurately controlled vehicle speeds, simulating synchronized tyre punctures/deflations and creating LIN communication errors so that subsequent repeat data requests etc. can be monitored. Key real-world problems such as slow deflations at high speed are extremely time consuming (tyres must be allowed to cool etc. after each test), but this LIN-based virtual solution allows all permutations to be tested at a fraction of the time/cost.



▲ *Schematic overview of the hardware-in-the-loop tests.*

Driver-in-the-Loop Simulation

In addition to HIL simulation, our proving phase also covers driver-in-the-loop simulations. MotionDesk, enabling 3-D animation in a virtual world, is used to allow virtual test-drives to be replicated in the laboratory. Together with our Volkswagen Group colleagues, we have digitally recreated the VW test facility Ehra-Lessien and exported this to MotionDesk with additional scenery etc., so that the test engineer can drive the same routes as our real prototype vehicles. This visualization tool allows key vehicle parameters to be evaluated, and changes in calibration can be immediately assessed at the overall vehicle response level. The virtual vehicle model and visualization also allow rapid conceptual changes to be easily validated.

> *"By using the dSPACE HIL system for the Continental GTC tyre-monitoring development, we reduced our software development time by 50% compared to previous projects."*
> ***Tom Fussey, Bentley***

Test Automation

The challenge we now face is to enable the test quantity and depth to be increased in line with system complexity. Therefore we have solutions in place to control all major driver inputs remotely, including throttle pedal actuation, steering-wheel angle, ignition switch status and gear lever position. CAN messages are also manipulated via the dSPACE Real-Time Multi-Message Blockset. As part of our test automation solution we use AutomationDesk to allow test engineers to efficiently create and monitor simple test scripts, primarily for our mobile automated failure insertion unit.

By using the dSPACE HIL system for the Continental GTC tyre-monitoring development, we reduced our software development time by 50% compared to previous projects.

Tom Fussey
Electrical Engineering
Bentley Motor Cars Ltd.
Crewe, Cheshire
United Kingdom

System-Level Simulation

- Simulating automotive software systems
- Closed-loop simulation supported
- Realistic, ECU-close simulation

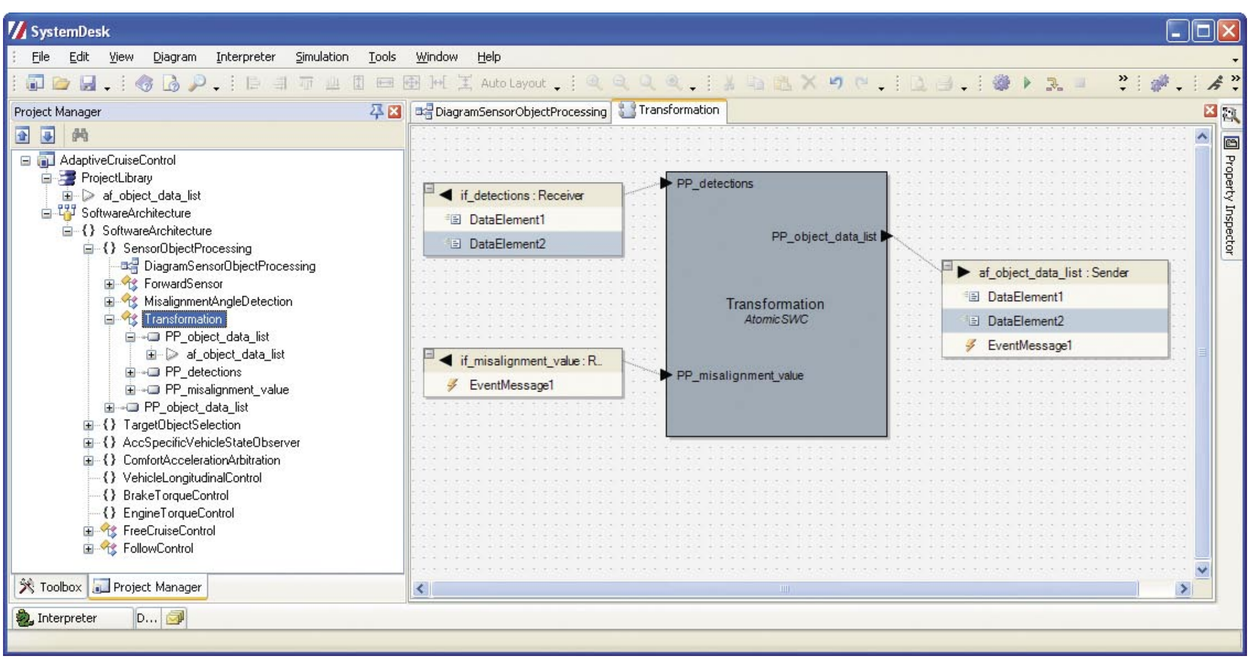
Errors in the logical links between functionalities are often not found until after the electronic control units (ECUs) are implemented by suppliers and integrated by the OEM. So if any errors occur in the modeling of new functionalities, they need to be identified in the early stages of the development process. With the SystemDesk Simulation Module, a vehicle manufacturer can detect any problems as early as the specification or implementation stage.

The new architecture tool SystemDesk can be used for model-based development right from system level. It supports tasks such as describing software architectures, defining hardware topologies, and mapping software components to hardware, whilst ensuring compliance with the AUTOSAR standard. In the near future, users will be able to simulate and verify ECU systems with SystemDesk.

Verifying the Software Architecture

For example, a vehicle manufacturer who wants to develop a control for a direction indicator can enter all the software components involved and their interconnections. To verify the behavior of the software architecture, the manufacturer can use SystemDesk to simulate the models and their implementations offline on a PC. Such simulations help to detect situations where all individual functions work correctly, yet problems occur in the system's overall behavior. SystemDesk will support open-loop and closed-loop simulation. Developers can also insert errors to analyze how the functionalities behave in critical situations. A useful feature for function designers is that after developing functions separately, they can test them as an overall system.

Sometimes software components have to be distributed to the actual ECUs in an early phase of development, for example, for bus simulation. For CAN



▲ *A model on the logical level. The design definition is repeatedly refined until it consists entirely of atomic functionalities.*

buses, effects such as arbitration or bus capacities can be simulated. This enables users to make a rough estimation of bus usage.
All SystemDesk's simulation options can be controlled via integrated scripting options or the COM-based automation interface. This allows users to integrate the simulation into their testing and development process and to automate test execution.

Integration of Plant Models

For closed-loop simulation at system level, both Simulink®-based plant models and other vehicle models can be imported by means of C code. This code is used to build a Windows® DLL, which is loaded to SystemDesk by the simulation engine. Both the ECU code and the plant model are simulated by the simulation engine. Simulink continues to be used at function level.

Testing the Implementation Models

Frequently, various parts of the overall system are developed by suppliers. And within OEMs, different development teams are responsible for different functions. It is therefore vital to test the overall system. In this stage of the development, the production ECUs are known, and the corresponding production code is available. Users can therefore simulate several new effects that are associated with production ECUs. The most important issues are:

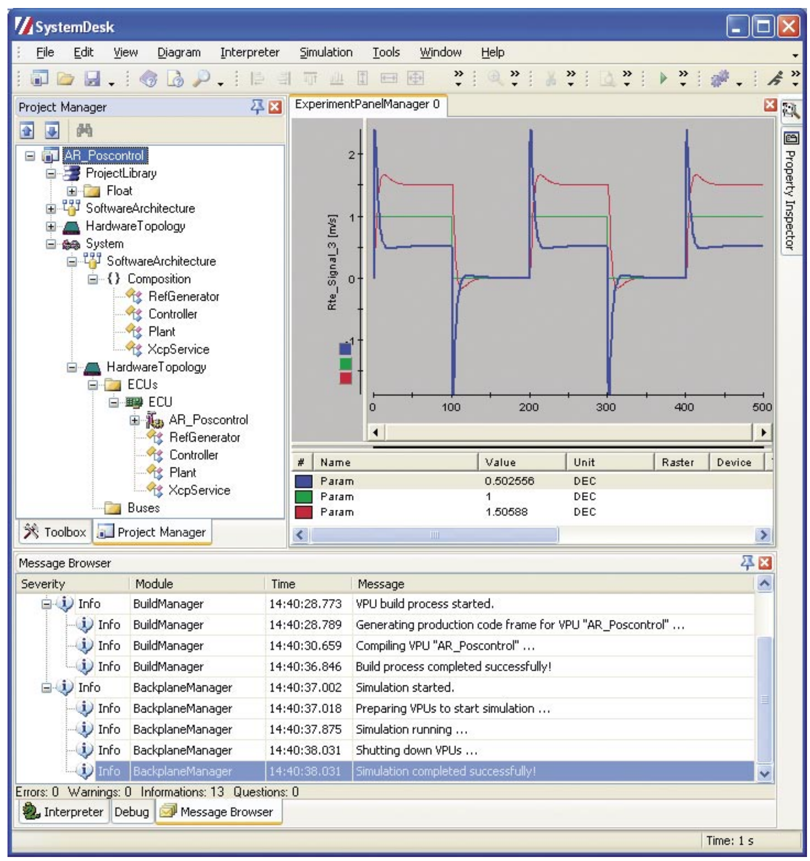
- Communication buses: testing bus capacities, failures, arbitration, and transfer times
- Integrating compiled object files for a specific processor (with evaluation boards)
- OSEK operating system simulation for simulating the application's scheduling behavior
- Fixed-point properties (such as scaling)
- Memory consumption (especially ROM and stack usage)
- Emulating the basic software

SystemDesk currently emulates the following basic software modules:

- Mode management: For example, simulating ECU power-up and shutdown
- Error management: Users can check which error codes have occurred during a simulation
- NV-RAM manager
- AUTOSAR COM layer
- Operating system

Summary

SystemDesk is designed for the model-based development process at system level, with a Simulation Module that supports the simulation of production code and plant models. It also allows the whole system to be simulated. Users can simulate and verify the behavior of the overall system at an early stage of the process. The simulations are extended in later development phases by simulation of the ECU behavior, implementation code, or communication buses. SystemDesk 1.0 will be released in the summer of 2007. The SystemDesk Simulation Module will follow in a later version.



▲ *Simulation run with SystemDesk.*

Glossary

Open-loop simulation –
This uses simple stimulus generators, constant values, or replays of recorded data.

Closed-loop simulation –
The ECU system must be connected with plant models.

AFDX for Airplanes

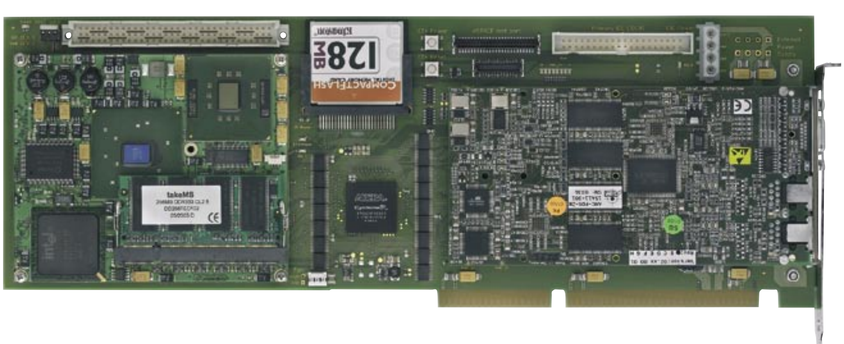
- AFDX interface for rapid control prototyping and hardware-in-the-loop simulation
- In addition to ARINC429 and MIL-STD-1553 support
- Customer-specific solutions on request

For the avionic and aerospace industry, dSPACE now offers the AFDX (Avionics Full Duplex Switched Ethernet) Solution Interface to connect a modular dSPACE system to an AFDX network. After ARINC429 and MIL-STD-1553, AFDX is the third avionic network protocol supported by dSPACE. It is based on the DS4504 board with an ETX (Embedded Technology eXtended) module working like an embedded PC.

The new AFDX Solution increases dSPACE's product range for the avionic and aerospace industry, adding support for another major avionic network protocol. For example, AFDX is used as a main data bus on the Airbus A380 and upcoming airplanes. The AFDX Solution can be used for rapid control prototyping (RCP) and hardware-in-the-loop (HIL) simulation, two procedures that are increasingly being used for developing and testing airplanes.

Based on DS4504 Board

The dSPACE AFDX Solution is based on the DS4504 board, which acts as a carrier for an ETX (an embedded PC) and a PCI Mezzanine Card (PMC). In principle the ETX works as an intelligent communication processor between a modular dSPACE system and the PMC module, which provides the AFDX interface, for example. Data exchange between the ETX and the dSPACE processor board runs via the PHS++ (peripheral high speed) bus and a 2-MByte dual-port memory (DPMEM), while the Peripheral Component Interconnect (PCI) bus handles data exchange between ETX and PMC. A Compact Flash (CF) card contains the QNX run-time operating system and the ETX application, for example, for AFDX.
The solution concept consists of:



▲ *The DS4504 Carrier board with its AFDX PMC module.*

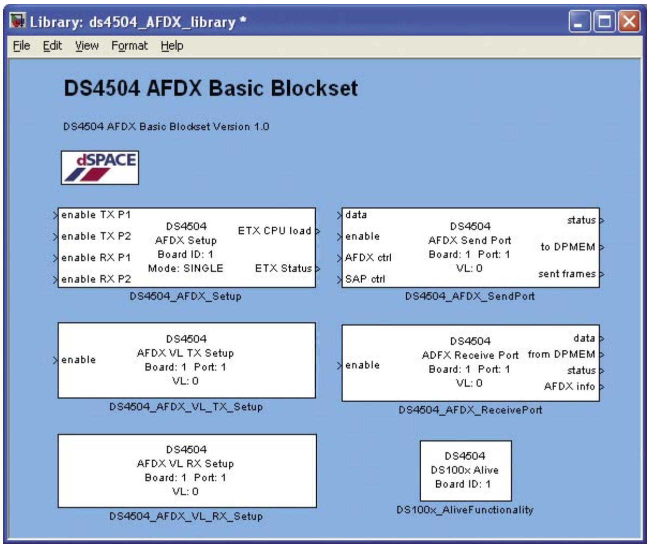
- Processor board (DS1005 PPC Board or DS1006 Processor Board, or a multiprocessor system) for the real-time application
- DS4504 with ETX module (containing a mobile Pentium IV processor with 1.1 GHz), the PMC board, and a CF card

Various dSPACE I/O boards, providing A/D, D/A, ARINC429 or CAN interfaces, can be added to the modular system.

▲ *The PMC Module AMC-FDX-2 for connection to the ADFX network.*

dSPACE AFDX Solution

AFDX is the main avionics databus network onboard the A380 and is based on commercial 10/100-Mbit, full duplex switched Ethernet. It uses a special protocol providing deterministic timing and redundancy management which ensures secure and reliable communication of critical and noncritical data. AFDX communication protocols were derived from commercial databus standards (IEEE802.3 Ethernet MAC addressing, Internet Protocol IP, User Datagram UDP) to achieve the deterministic behavior required for avionics applications. The dSPACE AFDX Solution, playing the role of an AFDX end system, enables you to interface your AFDX network directly to the real-time application running on the dSPACE processor board. The connection to AFDX uses an AIM PMC module and the corresponding QNX driver. AIM is a manufacturer of avionic test and simulation products.



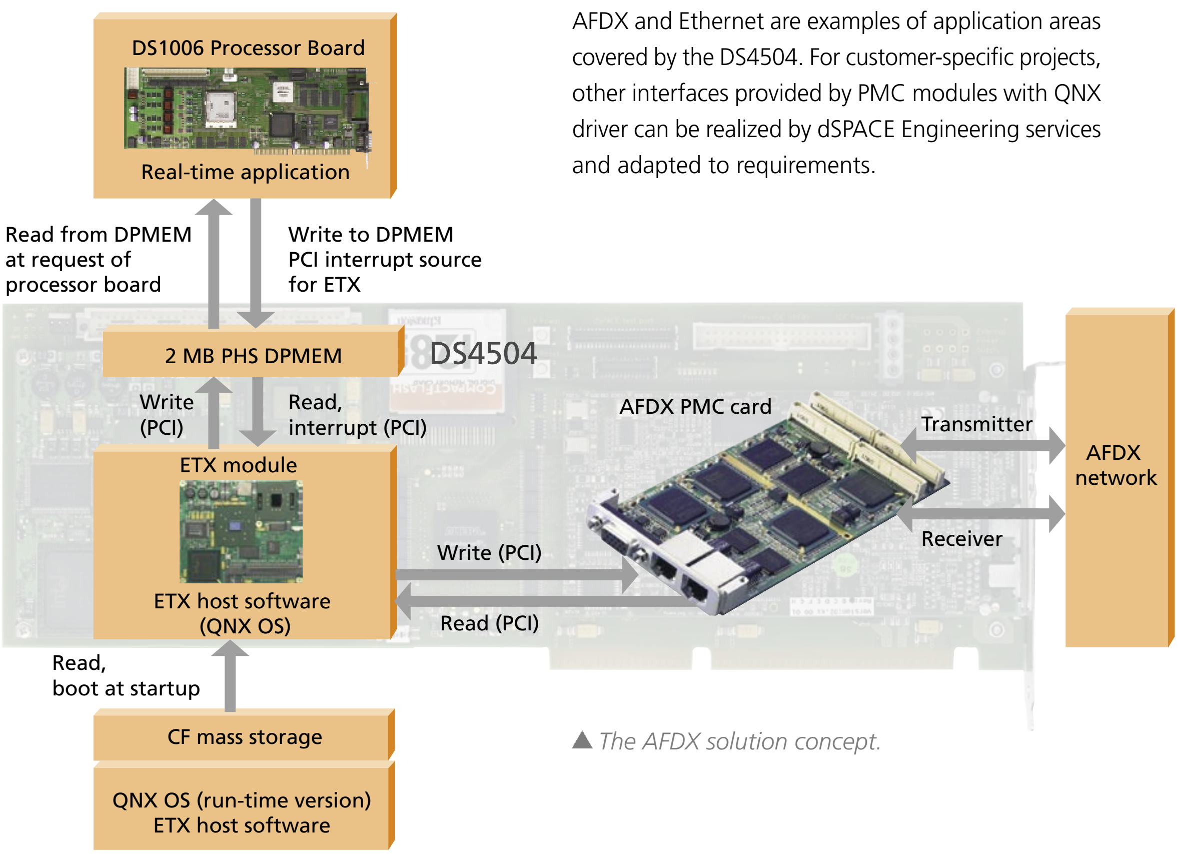
▲ *The AFDX Basic Blockset gives complete graphical support for configuring the AFDX board.*

The solution and the connection to the Simulink® model are configured graphically by means of the DS4504 AFDX Basic Blockset, based on S-functions. This Real-Time Interface (RTI) software helps you to configure general AFDX and board settings, and detailed virtual link and port settings.

Ethernet Solution

Also based on the DS4504 is dSPACE's 100-Mbit/s Ethernet Solution. The new 100-Mbit/s Ethernet Solution enables you to transmit data between dSPACE processor boards (DS1005, DS1006, or multiprocessor system) and a remote computer system. The UDP/IP and TCP/IP protocols are supported. Data transmission between the processor board and a customer-specific bus system can also be implemented by using an appropriate gateway computer connected to the Ethernet network. For example, in one specific customer project, an interface to a MOST (Maynard Operation Sequence Technique) network was implemented with the 100-Mbit Ethernet Solution using a special gateway.

AFDX and Ethernet are examples of application areas covered by the DS4504. For customer-specific projects, other interfaces provided by PMC modules with QNX driver can be realized by dSPACE Engineering services and adapted to requirements.



▲ *The AFDX solution concept.*

Automated Parameter Studies

- Script-based tool automation for ModelDesk
- Automated parameterization and experiment management
- Efficiency and convenience for parameter studies

Long-term tests and parameter studies can now benefit from script-based tool automation in ModelDesk, the parameterization software for the Automotive Simulatin Models (ASM). This offers users maximum flexibility to define custom simulation scenarios, utilizing scripting languages like Python and MATLAB M.

Tool Automation for ModelDesk

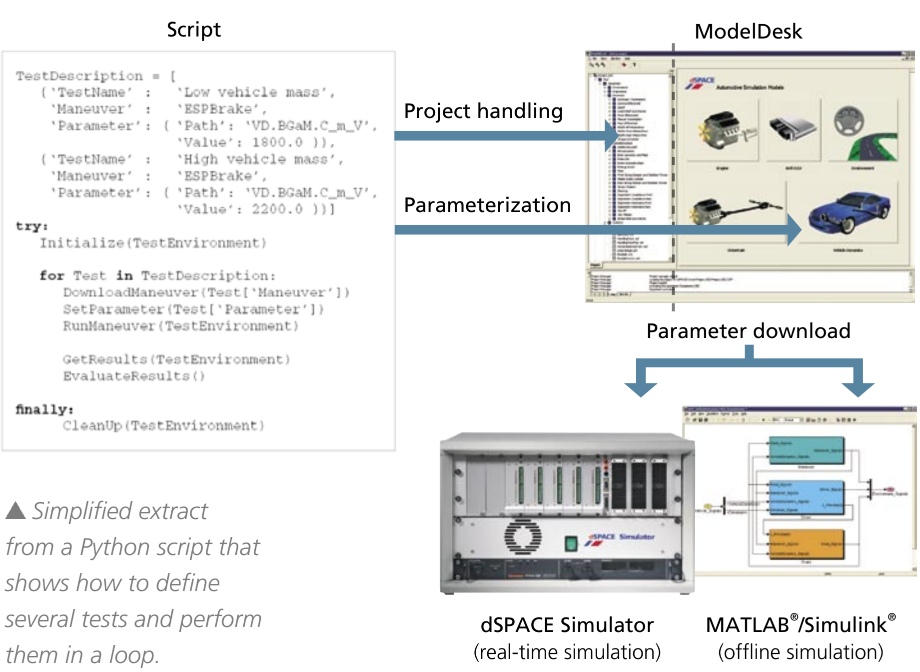
ModelDesk 1.1 supports remote control based on script languages such as Python and MATLAB M, and also AutomationDesk, the test automation software from dSPACE. The new feature is available under the name of tool automation and uses ModelDesk's COM interface (Microsoft COM, Common Object Model). It means that all functions for experiment management and vehicle or environment parameterization previously available via the GUI are now also available via a programmable interface. Thus, nearly everything that can be done manually by clicking buttons or entering values can also be executed from a script.

Use Cases for Tool Automation

Tool automation brings efficiency and convenience to parameter studies. As in real test drives, maneuvers can be performed repeatedly, varying certain conditions each time. This allows standard tests to run on a virtual basis before vehicle prototypes are available, and new control strategies to be tested without expensive physical infrastructures:

- Fishhook maneuver/rollover detection
  A short script that covers the following steps will be sufficient: set the test velocity, perform the fishhook maneuver, check if the tire lift exceeds the end condition, if not, increase the test velocity and restart. Once the tire lift condition is reached, the script can end the loop and save the test results.

- ESP corner braking
  Tool automation can also be used to check the vehicle stability controller (ESP) connected to a dSPACE Simulator under different conditions. The corner braking maneuver can be performed on a road repeatedly, with varying road frictions, test velocities, or additional loads on the vehicle, for instance. It is even possible to run the maneuver on corners with different radii by switching between predefined roads.



▲ *Simplified extract from a Python script that shows how to define several tests and perform them in a loop.*

Automated Results

The use cases illustrate how ModelDesk's tool automation helps to gather valuable data in early stages of the development process. The feature is seamlessly integrated into the dSPACE tool chain and can be used in offline simulation for developing new control algorithms and also for testing ECUs on a HIL simulator in real time.

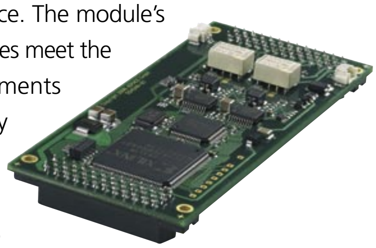
FlexRay Made Easy

The DS4340 FlexRay Interface Module and the DS4505 FlexRay Interface Board are two new products added to dSPACE's hardware for FlexRay applications to create a coordinated hardware package. Together, the boards are ideal for constructing FlexRay networks, and also for testing FlexRay applications such as restbus simulation. The DS4340 has a FlexRay communication controller that complies with FlexRay specification V2.1 and can be used with the MicroAutoBox as well as with the DS4505.

- **New FlexRay Interface Module**
- **Connection to FlexRay Communication System**
- **Carrier and Module from a Single Source**

DS4340 FlexRay Interface Module

The DS4340 FlexRay Interface Module is ideal for testing and networking safety-relevant functions that require a fast, real-time-capable, deterministic bus system. With the integrated communication controller of the MFR 4300 series from Freescale, the module supports FlexRay protocol specification 2.1. The carrier used for the module is either the DS4505 FlexRay Interface Board or MicroAutoBox. The DS4340 can also be used in conjunction with the previous version of the DS4505, the DS4501 FlexRay Interface. The module's technical features meet the tough requirements demanded by leading OEMs and suppliers in this field. These include:

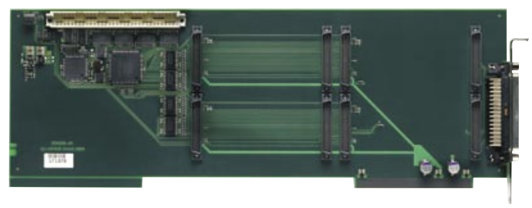


▲ *The DS4340 FlexRay Interface Module connects MicroAutoBox to a FlexRay bus system.*

- Connecting the bus signals through for minimum connection distance
- Switchable termination

DS4505 FlexRay Interface Board

The DS4505 FlexRay Interface Board was developed especially for the DS4340 FlexRay Interface Module and supports up to four such modules. An optimized hardware interface to the DS4340 cuts the time needed to access the FlexRay controller, freeing up time reserves for computations on the processor boards. The new board is ideal for rapid control prototyping and also for testing FlexRay applications with a dSPACE Simulator. This works equally well whether the connected system uses a DS1005 PPC Board or a DS1006 Processor Board.



▲ *The DS4505 FlexRay Interface Board can be equipped with up to four DS4340 FlexRay Interface Modules.*

Used with MicroAutoBox

The DS4340 FlexRay Interface Module can also be used without the DS4505. The MicroAutoBox supports up to two of these modules. Thanks to MicroAutoBox's unique combination of powerful, comprehensive automotive I/O and compact, robust design, it can be used for prototyping inside the actual vehicle.

dSPACE FlexRay Configuration Package

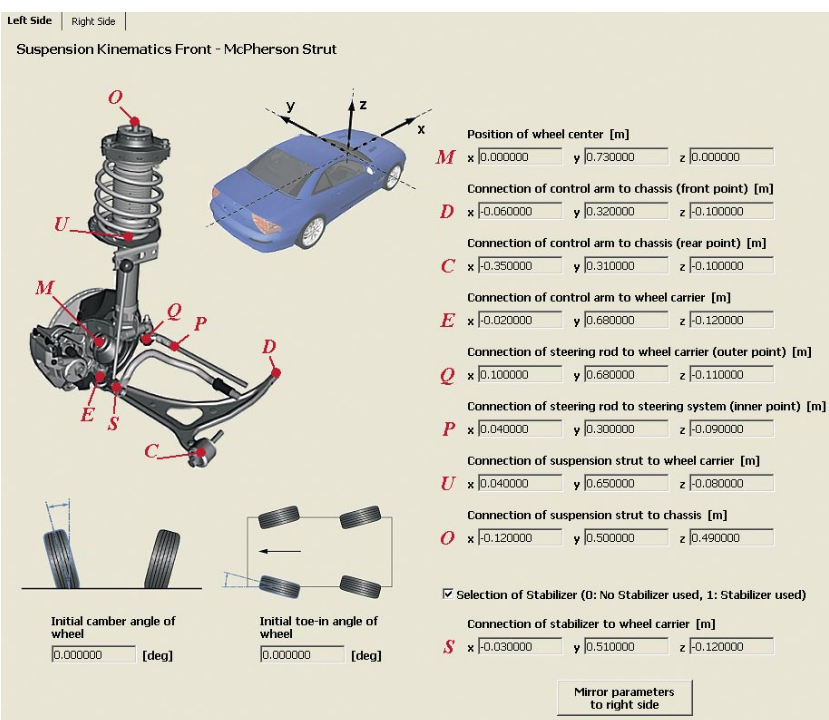
The dSPACE system is integrated into the bus communication by the dSPACE FlexRay Configuration Package, which reads in the network description from a FIBEX file. Users configure the communications and generate Real-Time Interface (RTI) blocks for their Simulink® environment. Thus, everything needed for easy and efficient modeling in MATLAB®/Simulink is available. A click starts the build process with automatic code generation and code integration, right through to the final, executable program for the real-time process. The nodes of the FlexRay network are configured with the FlexRay Configuration Tool according to the communication matrix, which contains the schedule for the signals to be transmitted via the FlexRay bus. This guarantees real-time support during ECU development in the FlexRay network.

Geometrical Suspension Models

- Extensions to ASM axle models
- Asymmetrical kinematics look-up tables
- Geometrical suspension models

Two major extensions for simulating wheel suspensions come with Version 1.3 of Automotive Simulation Models (ASM) from spring 2007: These are wheel suspension models that can be parameterized asymmetrically, and models with geometrical descriptions of the axle kinematics. All axle types can be parameterized simply in graphical form via ModelDesk.

One method of simulating wheel suspensions with the ASM – Vehicle Dynamics Simulation Package is to collect measurement data (for example, from kinematics & compliances (K&C) test benches or from multibody simulation (MBS) tools such as ADAMS/Car) and integrate it into the model via look-up tables. The tables describe the kinematics of a wheel suspension as functions of spring compression, steering, etc. The compliances in the wheel suspension are simulated by overlaying suitable look-up tables.



▲ *Convenient parameterization of a McPherson wheel suspension with ModelDesk.*

Asymmetrical Parameterization of Kinematics Look-Up Tables

Version 1.3 of ASM now allows asymmetrical axle kinematics to be implemented, in addition to the table-based symmetrical wheel suspension parameterization already available. The ModelDesk parameterization software detects dynamically which axle variant is used, and allows parameters to be assigned to the look-up tables.

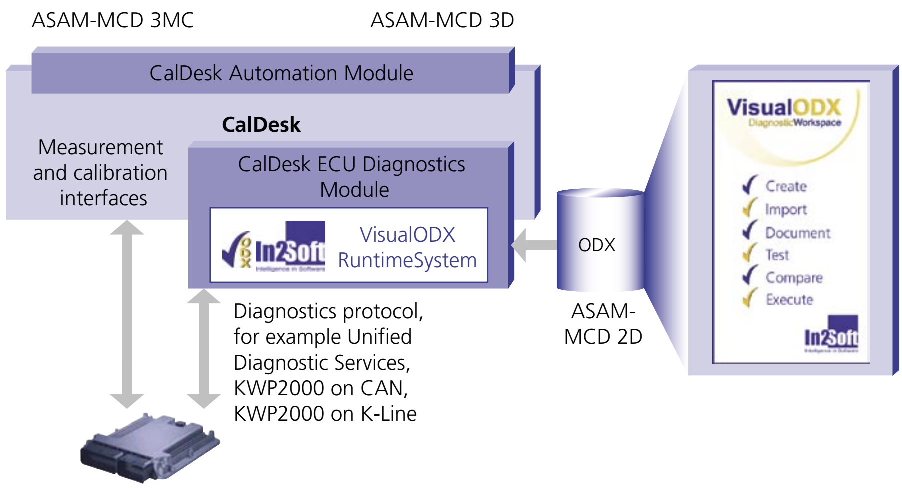
Geometrical Axle Descriptions

A completely new kind of axle simulation is provided by the geometrical wheel suspension models. The axle kinematics are not represented by look-up tables, but implemented as formulas and calculated analytically in each simulation step. The particular advantage of geometrical descriptions of axle kinematics is that they do not require measurement data. Instead, they can be simply parameterized graphically in ModelDesk. This is done by configuring the relevant geometrical linkage points connecting the steering rods to the wheel carrier and the chassis. The analytical modeling approach allows the linkage points to be modified freely during run time, and also ensures that the entire value range of the input variables is covered, so no interpolations or extrapolations are necessary. The geometrical axle descriptions include the well-known axle types McPherson strut, semi-trailing arm, and rigid axle. To take the bearing compliances in the wheel suspensions into account, the geometrical axle models can be overlaid with appropriate look-up tables.

Cooperation with In2Soft

dSPACE and In2Soft GmbH are cooperating on ECU diagnostics integration into CalDesk, dSPACE's universal and scalable measurement and calibration tool. The In2Soft VisualODX RuntimeSystem was completely integrated into the CalDesk ECU Diagnostics Module via the standardized automation interface ASAM-MCD 3D. Thus, dSPACE enables users to use the same tool for measurement, calibration, and diagnostic tasks, from a single tool supplier.

The VisualODX RuntimeSystem, and therefore diagnostics support in CalDesk, are based on the ODX standard (ASAM-MCD 2D), so they require appropriate ODX data. As a specialist in vehicle diagnostics, In2Soft designed VisualODX to provide a complete tool chain for working with diagnostic data in ODX format. The In2Soft DatabaseDesigner is one of the most flexible and powerful ODX editors on the market today, and is used by major vehicle manufacturers (such as VW, Audi, MAN), who recommend it to suppliers as a reference for creating ODX data. In addition, VisualODX enables users to check, execute, and document ODX data, and to compare it with other ODX data.



A Selection of Innovations in Release 5.3

Product	Innovation
AutomationDesk 1.5 (with Real-Time Testing 1.1)	■ Support of DS1005 PPC Board and single nodes of multiprocessor systems for Real-Time Testing
ControlDesk 3.1	■ New CAN Navigator features: ■ CAN bus data monitoring (raw data) ■ CAN bus data logging ■ Conversion of IDF files larger than 2 GB
ModelDesk 1.1	■ Tool coupling with MotionDesk. When ModelDesk downloads a road, the MotionDesk scene is updated automatically. ■ Script-based tool automation. For more details about tool automation, please see article on page 24.
MTest 1.5	■ Using Classification Tree Editor (CTE) for reference data specification
RTI Bypass Blockset 2.2.2	■ Support of DS2202, DS2210 and DS2211 concerning bypassing via CCP and XCP on CAN. ■ XCP on CAN gateway functionality for arbitrated access to ECUs from several tools at the same time, even if only one XCP service instance is implemented on the ECU.
RTI LIN MultiMessage Blockset 1.2	■ Extended sleep support (Tx and Rx of go-to-sleep command) ■ New test features for run-time tests, e.g. ■ Dynamic LIN frame checksum for n times ■ Corruption of break length and break delimiter ■ Variation of baud rate

For more informationen, please visit *www.dspace.com/goto?releases*

Global HIL Strategy at General Motors

- dSPACE selected as the global HIL supplier for GM since early 2005
- GM uses dSPACE Simulators in 10 countries spanning 4 continents
- HIL testing for hybrid propulsion systems

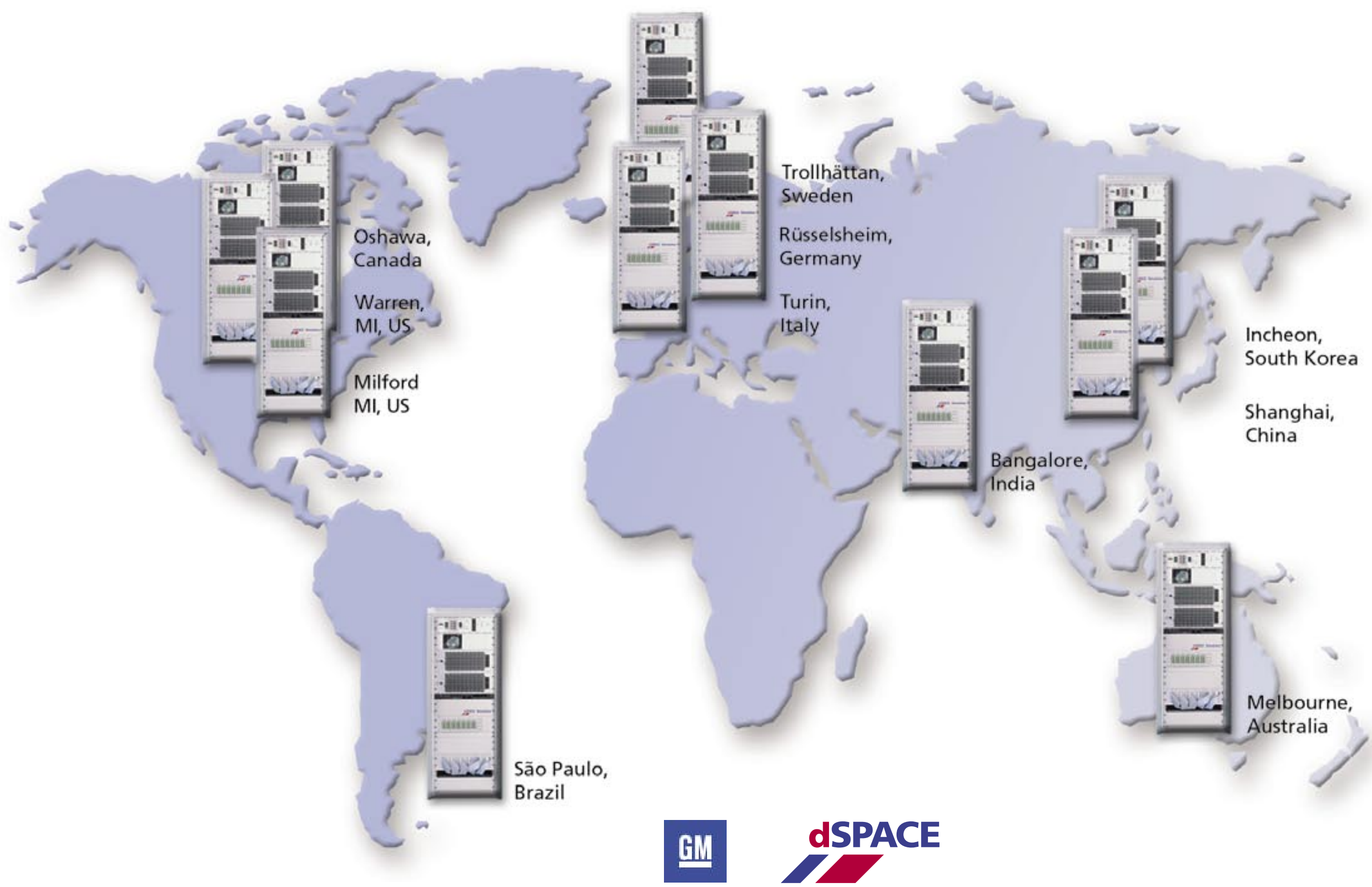
In a thorough evaluation process for hardware-in-the-loop (HIL) solutions two years ago, dSPACE Simulator was chosen as the global HIL solution for General Motors. Currently, GM employs dSPACE Simulators in over ten countries, in various applications such as electrical, chassis, and hybrid propulsion systems. The simulators support a varying range of ECUs in a given category, which is a key requirement of GM's Combo HIL concept.

Looking Back

About two years ago GM completed a complex evaluation of HIL test solutions from a number of potential suppliers. One of their aims was to find the best test equipment to meet the requirements of GM's global HIL strategy. Open- and closed-loop operation, an optional failure insertion unit, and easy duplication of benches were major criteria. Additionally, business aspects such as openness and worldwide supply chain were very important for a global company like GM.

Upon completion of the evaluation, dSPACE was selected as GM's global supplier for new HIL systems (see dSPACE NEWS 1/2006). "dSPACE HIL technology emerged on top after a thorough selection process", says Mike Barrera, HIL Tools Leader, GM US. The evaluation led to a multi-year contract defining important components of the cooperation.

▼ *As of May 2007 dSPACE Simulators are used in technical centers spanning ten countries in four continents.*



Worldwide Deployment

As of May 2007, General Motors will employ numerous dSPACE HIL systems in its worldwide technical centers, spanning ten countries in four continents: Australia, Brazil, Canada, China, Germany, India, Italy, South Korea, Sweden, and US. Most of GM's major technical centers around the world are equipped with dSPACE Simulators. This impressive growth within the first two years has led to a situation where at any time, day or night, somewhere in the world a GM employee is working with dSPACE equipment – and dSPACE is working hard to ensure that more GM employees will be involved in the future. "dSPACE is a globally operating company, which suits the global structures of GM very well. The dSPACE HIL systems are flexible, robust, and expandable and therefore well accepted in all application areas", comments Mina Khoee-Fard, Engineering Group Manager, GM US.

The Combo HIL Concept

For powertrains especially, GM relies on a combo HIL strategy that allows the systems to be used flexibly and provides a solid basis for global operation with distributed test activities around the world. The idea is that each HIL system is to a certain extent universal, so that multiple ECUs of a defined category can all be tested on it. The advantage is that multiple teams share the same simulator, resulting in a high level of utilization and improved return on investment. The combo concept allows stand-alone systems to be integrated into other benches; for instance, a transmission HIL integrates into a hybrid bench. All the dSPACE HIL systems at GM can be upgraded to meet new requirements. "The flexibility and expandability of the combo HIL concept extends the lifetime of assets," is how Mike Barrera sums up the advantages of GM's HIL strategy.

Applications and Utilization

A breakdown according to application shows that 40% of the systems are used for testing powertrain ECUs, 40% for electrical systems, and 20% for chassis controls/vehicle dynamics. Several HIL systems are in use in new hybrid propulsion projects.

"My experience has shown that dSPACE is the leading provider for integrated real-time test systems," says Dr. Hamid Oral, The Lead Controls Test Engineer from GM Hybrid Powertrain," and my team looks forward to using the dSPACE systems for the upcoming projects," he added.

David Colbin, Engineering Group Manager, GMPT Sweden, explains, "It is vital for us to know how components will behave during failsofting or other stressing conditions. The HIL systems from dSPACE make it easier to discover serious problems."

"We have several flexfuel engine controllers being tested with the dSPACE HIL system in Brazil. It gives us an easy and reliable way to find any ECU misbehaviors prior to the launching", comments Vanessa Aiello, Product Engineer, GM Brazil, on her experience.

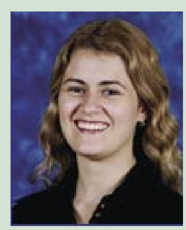
Looking Forward

The reliable operations of the HIL systems during the past two years are the basis for good future prospects. "dSPACE keeps pace with GM's ongoing development, providing suitable tools for new projects," says Mike Barrera. "Our close contact with dSPACE is an exciting opportunity to jointly prepare the way for new technologies."

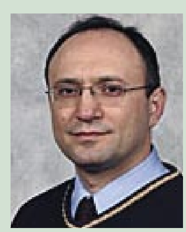
"GM requires a huge number of specialized test solutions in all application areas resulting in numerous custom developments. dSPACE's ability to respond quickly to GM needs is a win-win situation for both companies," summarizes Mina Khoee-Fard.

Mina Khoee-Fard, Engineering Group Manager, GM US

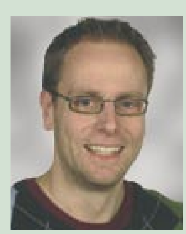
Mike Barrera, HIL Tools Leader, GM US



Vanessa Aiello, Product Engineer, GM Brazil



Dr. Hamid Oral, Lead Controls Test Engineer, GM Hybrid Powertrain US



David Colbin, Engineering Group Manager, GMPT Sweden

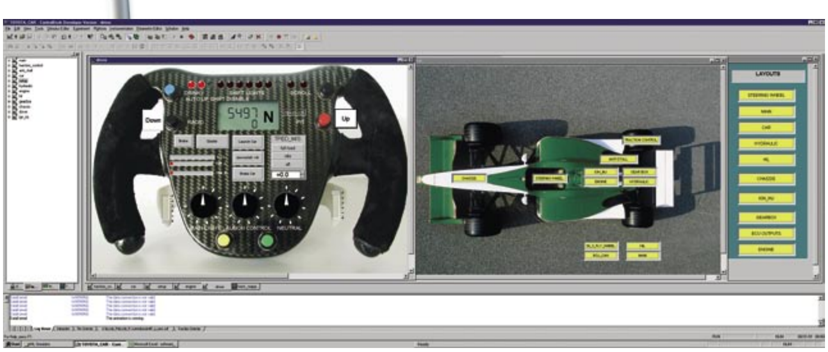
HIL in Formula One

- dSPACE HIL simulation for Formula One teams
- Used by almost all racing teams
- Ideal for tough requirements

Almost all Formula One teams use hardware-in-the-loop (HIL) simulators from dSPACE to develop and test their electronic control units, both individually and when networked. To simulate racing car models in real time, powerful and flexible-to-adapt hardware and software from dSPACE is used as a basis for real-time applications. Working closely with customers, dSPACE develops application-specific systems that are precisely tailored to the requirements of Formula One.

HIL Simulation in Motor Sports

Formula One teams produce new versions of their electronic control units (ECUs) on an almost daily basis, relying on hardware-in-the-loop simulation to test how the ECUs interact with the other components and software versions. Almost all teams use dSPACE simulators to calculate and simulate the racing car models. These virtual real-time tests ensure that both hardware and software are of the greatest possible quality before test drives are made with the expensive vehicles themselves. In many cases, HIL simulation is a fixed part of a team's testing processes. Only software versions that have passed the HIL tests are validated on test bench and test track. Cornering speeds and gear-change speeds can be increased only if the control systems for transmission, differential, and throttle are sufficiently fast. Gear changes take less than 20 ms, for example, and top speeds of 350 km/h demand very fast control loops. A high data transmission rate is enormously important, so the CAN buses always use the highest baud rate of 1 Mbit/s.



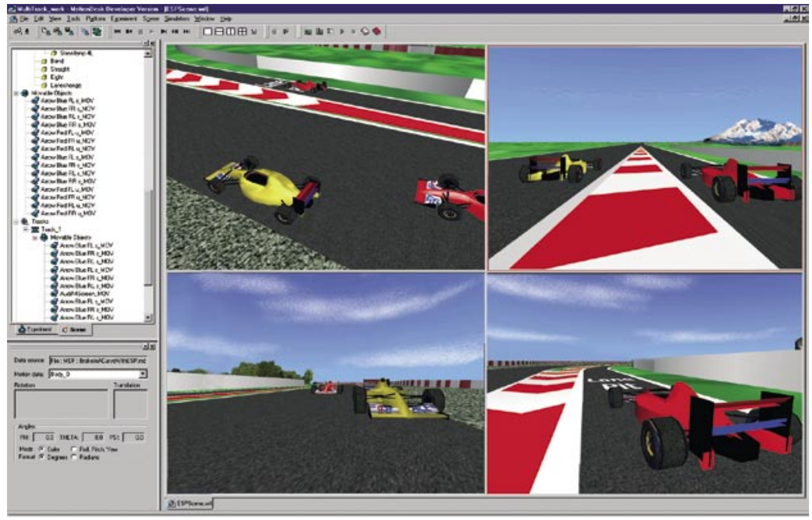
▲ *Graphical user interface for motor sports in ControlDesk.*

Model Calculation and I/O Signals

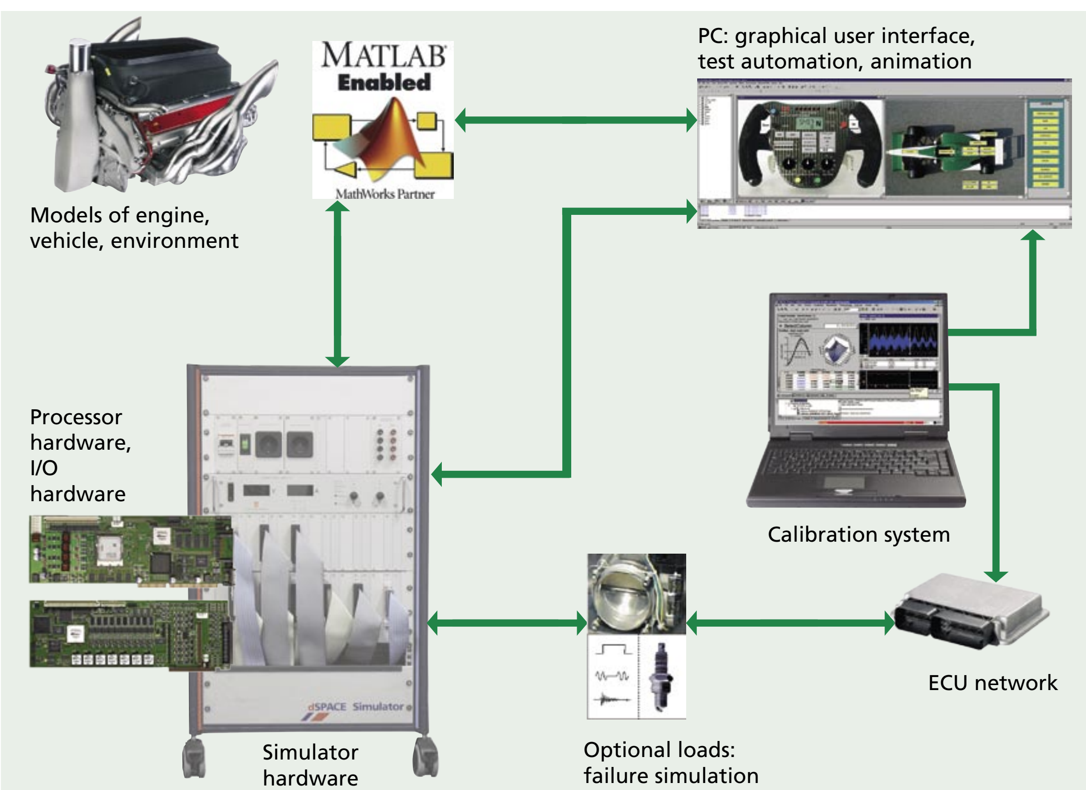
The DS1006 Processor Board with a clock rate of 3 GHz is ideal for calculating the complex models of racing cars. If necessary, developers can combine several DS1006 boards to make a multiprocessor system with very short computation times, for example, to calculate a mean-value engine model, a brake hydraulics model, and a vehicle dynamics model, including the entire I/O for engine and vehicle dynamics control. The DS2211 HIL I/O Board implements the application-specific engine signals. For example, it calculates the crankshaft and camshaft signals synchronously with the engine angle, and simultaneously measures the injection times and the ignition angle synchronously with the crankshaft angle. In the automotive industry, the board is widely utilized for passenger vehicles and trucks. With a 4 MHz update rate for the angular processing unit (APU) bus, it fits the requirements of Formula One perfectly. It provides all the necessary I/O connections for a combustion engine with a maximum engine speed of +/- 29,296 rpm, and up to 8 cylinders, including signal conditioning. Higher counts of 10, 12, or 16 cylinders can be achieved by cascading DS2211 boards. The dSPACE simulator can be extended by an arbitrary number of CAN interfaces. Capturing all CAN messages from the ECU network, and CAN restbus simulation for emulating unavailable network nodes, are typical tasks. This is particularly important if the chassis and the engine are being developed at separate locations, as is currently the case with world champion Renault, for example (see dSPACE NEWS 2/2005).

Graphical Animation

The real-time model of the racing vehicles are implemented on the real-time test hardware via dSPACE's Real-Time Interface (RTI). RTI provides extensive Simulink® block libraries for defining analog and digital I/O connections, and for more complex systems such as CAN communication and crankshaft-angle-based I/O functions. dSPACE's 3-D animation software MotionDesk shows the vehicle behavior on screen, for example, if the car skids on a bend or how it brakes on different road surfaces. Several simulations can be played back synchronously in multi-track mode, so developers can compare them directly and choose the best control strategy. Users can even drive the simulated vehicle themselves, by connecting a real steering-wheel and real pedals to the simulator. They are also given visible and audible feedback such as engine noise. To reproduce specific operating points precisely, testers can take data recorded during actual drives and run it in lab tests. This helps them to reproduce and study specific critical situations. The test system is handled via ControlDesk's graphical interface, which users can adapt to fit specific projects. To allow comparison, simulated test drives must be precisely reproducible, and must preferably also run automatically. Both goals are achieved by AutomationDesk, the test management and automation software. This enables users to create test runs graphically without needing particular programming knowledge. Further advantages are integrated test management, a powerful tool for creating customer test libraries, results management, and integrated reporting.



▲ MotionDesk shows the driving maneuver on screen.



▲ *Typical structure of a hardware-in-the-loop test system for racing cars.*

Industry Partnerships Enrich Programs

- Lawrence Tech partnering with industry leaders
- Working engineers share real-world insight
- Tools give students hands-on lab experience

Lawrence Technological University (Southfield, MI) is partnering with industry-leading companies to help define its core curriculum offerings for two graduate academic programs – Master of Science (M.S.) in Automotive Engineering and Master of Science in Mechatronic Systems Engineering, a new degree program established in 2006. These partnerships give students first-hand insight into modern-day solutions that are being embraced by manufacturing industries around the globe. dSPACE Inc. is one of these companies helping to prepare tomorrow's engineers for today's challenges.

Lawrence Technological University (Lawrence Tech) is equipping its engineering students with the methodologies, disciplines and tools necessary to succeed in the rapidly evolving field of Automotive Controls and Engineering of Mechatronic Systems for various industries by going straight to the source – the industry leaders who are defining the technologies of the future. The university (based in Southfield, Michigan, USA) has adopted a novel approach to balancing text book theories with hands-on application experience by partnering with working industry professionals. Lawrence Tech has established academic partnerships with dSPACE, major automotive OEMs and other industry leaders to leverage real-world insight and guidance for its Master of Science (M.S.) in Mechatronic Systems Engineering and Master of Science in Automotive Engineering graduate programs. In addition to providing advice on current industry trends and needs, the university's academic partners frequently serve as guest lecturers in the classroom. This provides an ideal opportunity for students to learn about design and manufacturing issues first hand, from experienced engineers working in the field.

▲ *Lawrence Tech professors meet with dSPACE employees to discuss academic partnership opportunities. Pictured left to right are: dSPACE Inc. senior applications engineers Donald Saldano and Shahriar Kamal; Lawrence Tech professor Dr. Suresh Bansal, Lawrence Tech lecturer Dr. Joseph Asik; and dSPACE Inc. technical specialist Bob Gruszczynski.*

"With the involvement of our academic partners, we're exceeding our own expectations (for these programs)," said Dr. Suresh Bansal, Director of the M.S. Automotive Engineering program and Automotive Engineering Institute at Lawrence Tech. "Partnering with industry leaders brings a whole new element to the learning experience. This is a new concept for American academic institutions and the educational possibilities are invaluable."

Four-Wheel Drive Chassis Dynamometer

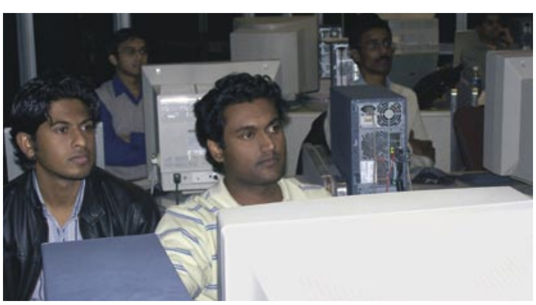
Outside of the classroom, Lawrence Tech students are exploring innovative automotive engineering solutions through the university's recently acquired four-wheel drive vehicle chassis dynamometer. The dynamometer is equipped with individual wheel torque electronic controls. This unique feature enables power distribution to be applied independently to each wheel, which in turn makes it possible to incorporate a much broader and diverse range of testing scenarios. The dynamometer has capabilities in such areas as: vehicle traction control; turnability and ride stability; acceleration and braking; all-wheel driveline system performance; diagnostic testing; noise and vibration systems; safety systems; fuel efficiency improvement; and emissions testing. The dynamometer is being used actively for class projects and industry research.

M.S. in Automotive Engineering

Graduate students pursuing a master's of science in automotive engineering are eligible to enroll in Lawrence Tech's new, two-course series on Automotive Control Systems. The specialized program focuses on developing and applying modern controls for complex vehicle systems. Dr. Bansal, who directs the program, said his students are incorporating modeling, rapid prototyping, hardware-in-the-loop simulation and other advanced concepts to design control systems for dynamic vehicle behaviors, such as traction control, stability control, steering, driveline systems and intelligent cruise control. dSPACE Senior Applications Engineer Don Saldano frequently serves as a field instructor for the automotive control systems program. He said dSPACE tools are used for project implementations in a real-time laboratory environment. "We're exposing students to the technical solutions of the future," Saldano said. "We're sharing strategies, tools and techniques for achieving resolutions. We're letting them know what's out there in terms of new capabilities."

M.S. in Mechatronic Systems Engineering

As the use of mechatronics is becoming commonplace across the global manufacturing landscape, the need for mechatronic systems engineers is at an all-time



▲ *Student engineers enrolled in Lawrence Tech's Automotive Control Systems-1 course listen to final project presentations given by their fellow classmates.*

high. In response to the industry's growing demand for such specialized expertise, the university launched a new master's degree program in mechatronic systems engineering in the fall of 2006. Lawrence Tech

▲ *Lawrence Tech's four-wheel drive chassis dynamometer gives students an optimum platform for exploring innovative automotive engineering solutions.*

is the only university in the State of Michigan and one of a few universities in the United States offering a graduate-level degree in this field. "Industries understand that we need mechatronics – not today, but yesterday," said Dr. Vladimir Vantsevich, director of the M.S. Mechatronics Systems Engineering program and Mechanical Engineering Department at Lawrence Tech . "Mechatronics degree programs are popular in Europe and Asia, but there are very few in the United States. We are proud to offer such a program

"Partnering with industry leaders brings a whole new element to the learning experience."

Dr. Suresh Bansal, M.S. Automotive Engineering program director, Lawrence Tech

here at Lawrence Tech." The core curriculum for this graduate-level program was designed with the direct input of the university's academic partners, and covers all aspects of the synergistic design of mechatronic systems.

Through in-kind donations of equipment, software and other tools, Lawrence Tech recently established a state-of-the-art mechatronics laboratory to support its program. This is where students are taking methodologies learned in the classroom and applying them to hands-on engineering projects. Dr. Vantsevich noted that practicing engineers from various industries are actively enrolling in the mechatronics graduate program. All classes are scheduled during evening hours to accommodate working professionals. Scholarships are available for some prospective students.

For more information, visit *www.ltu.edu/engineering/mechanical/mechatronics.asp*

New TargetLink Modeling Guidelines

The aim of the TargetLink Modeling Guidelines is to ensure a seamless transition from function development to the automatic generation of highly efficient production code. The TargetLink Modeling Guidelines achieve this is by specifying items such as a suitable language subset of MATLAB®/Simulink®, rules for transparent controller layout, and optimum settings for code generation options in TargetLink. TargetLink Modeling Guidelines Version 2.0 is now available, providing updates connected with new MATLAB and TargetLink versions, plus suggestions on designing AUTOSAR software components, which are supported from TargetLink 2.2.

TargetLink users can obtain the Modeling Guidelines free of charge from Technical Sales at *info@dspace.com*

US Technology Journalists Visit dSPACE

Seven American journalists working in the automotive technology field visited leading automotive suppliers throughout Germany, one them dSPACE, as part of the German Media Tour 2007 in March.
President Dr. Herbert Hanselmann brought the guests up to date on the latest technologies used in developing automotive control systems. They were particularly impressed by the positive results that leading OEMs achieved using dSPACE test systems. They were also given a peek at the future, with Dr. Hanselmann's presentation on the Architecture-Driven Software Development of Automotive ECUs. Their visit culminated in an invitation to the DaimlerChrysler Museum, before they flew back to the USA.

▲ *End-of-trip visit to the DaimlerChrysler Museum (counterclockwise): Maggie Beauregard, John Day, William Diem, Christopher A. Sawyer, Steve Plumb, Byron Pope, Terry Costlow, Bruce Pollock.*

Cooperation with Elektrobit

ELEKTROBIT

dSPACE and Elektrobit Automotive Software, formerly known as 3SOFT, are cooperating on producing AUTOSAR-compatible control unit software. In the AUTOSAR software architecture, Elektrobit's tresos® ECU covers the creation and configuration of the basic software, and dSPACE's SystemDesk the application layer and the system design. The closely coupled tools give customers a thoroughly and interactively tested tool chain for all AUTOSAR development steps, and far-reaching added value. The interplay between the two tools is based on standard AUTOSAR file formats.

Hybrid Technology with dSPACE

Numerous manufacturers and universities presented their latest technologies and solutions at the conference on "New Electrical Drive Concepts for Hybrid Vehicles" at the Haus der Technik in Munich on March 20-21. The objective of the event was to demonstrate the potential for cost reduction and fuel savings, plus additional functionalities. Jürgen Klahold, product engineer at dSPACE, presented dSPACE products for testing electronic control units (ECUs) to interested engineers. The products enable developers to test both single ECUs for electric machines and ECU networks for entire hybrid propulsion units.

Events

EUROPE

Sensor + Test 2007
May 22-24, Nuremberg, Germany
www.sensor-test.de

5th dSPACE German User Conference
June 13/14, Munich, Germany
www.dspace.com

USA

2007 American Control Conference
July 11-13, New York, NY, USA
www.a2c2.org/conferences/acc2007

AUVSI's Unmanned Systems North America 2007
August 6-9, Washington D.C., USA
www.auvsi.org/symposium/index.cfm

AIAA Guidance, Navigation and Control Conference and Exhibit
August 20-23, Hilton Head, SC, USA
www.aiaa.org

AIAA Modeling and Simulation Technologies Conference and Exhibition
August 20-23, Hilton Head, SC, USA
www.aiaa.org

SAE 2007 AeroTech Congress & Exhibition
September 17-20, Los Angeles, CA, USA
www.sae.org/events/atc/

ASIA

ESEC - 10th Embedded Systems Expo & Conference
May 16-18, Tokyo, Japan
www.esec.jp/ESEC/en

dSPACE Japan K.K. User Conference
June 22, Ebisu, Tokyo, Japan
www.dspace.jp

JSAE 2007
May 23-25, Yokohama, Japan
www.jsae.or.jp

Automotive Testing Expo China
September 12-14, Shanghai, China
www.testing-expo.com/china/

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Job Opportunities

Due to our continuous growth, dSPACE is looking for engineers in

- Software development
- Hardware development
- Applications
- Technical sales
- Product management
- Technical writing
- User documentation

Current offers at *www.dspace.com/goto?jobs*

Papers

"One-Stop Solutions - ECU Test and Diagnostics Converging"
Dr.-Ing. Klaus Lamberg, Dipl.-Ing. Dirk Fleischer, dSPACE GmbH

"System Verification Throughout the Development Cycle"
Dr.-Ing. Rainer Otterbach, Dr.-Inf. Oliver Niggemann, Dipl.-Inf. Joachim Stroop, Dr.-Inf. Axel Thümmler, Dr.-Ing. Ulrich Kiffmeier, dSPACE GmbH

Trainings

- dSPACE Real-Time Systems
- ControlDesk
- RapidPro
- TargetLink
- Hardware-in-the-Loop-Simulation
- ASM Vehicle Dynamics
- ASM Engine Simulation
- AutomationDesk
- RTI CAN MultiMessage Blockset
- CalDesk
- Rapid Control Prototyping with CalDesk

For more information, please visit *www.dspace.com/goto?training*

Australia
CEANET Pty Ltd.
Level 5, 15 -19 Bent Street
Sydney NSW 2000
Australia
Tel.: + 61 2 9232 3699
Fax: + 61 2 9232 3332
info@ceanet.com.au
www.ceanet.com.au

China and Hong Kong
HiRain Technologies
8F Tower B
Beijing Venture Plaza No.11
Anxiang Beili Chaoyang District
Beijing China, 100101
Tel.: +86 10 648 40 606
Fax: +86 10 648 48 259
xmcao@hirain.com
www.hirain.com

Czech Republic and Slovakia
HUMUSOFT s.r.o.
Pobrezni 20
186 00 Praha 8
Tel.: +420 2 84 01 17 30
Fax: +420 2 84 01 17 40
info@humusoft.cz
www.humusoft.cz

India
Cranes Software Intern. Ltd.
#29, 7th Cross, 14th Main
Vasanthnagar
Bangalore 560 052, India
Tel.: +91 80 22381740
Fax: +91 80 22384317
dspace@cranessoftware.com
www.cranessoftware.com

Korea
MDS Technology Co., Ltd.
15F Kolon Digital Tower Vilant 222-7
Guro-3-dong, Guro-gu
Seoul 152-848, South Korea
Tel.: +82 2 2106 6000
Fax: +82 2 2106 6004
dspace@mdstec.com
www.mdstec.com

Netherlands
TSS Consultancy
Rietkraag 37
3121 TC Schiedam
Tel.: +31 10 2 47 00 31
Fax: +31 10 2 47 00 32
info@tsscon.nl
www.tsscon.nl

Poland
Technika Obliczeniowa
ul. Obozna 11
30-011 Kraków
Tel.: +48 12 630 49 60
Fax: +48 12 632 17 80
info@tobl.com.pl
www.tobl.krakow.pl

Sweden
Fengco Real Time Control AB
Svärdvägen 25A
SE-182 33 Danderyd
Tel.: +46 8 6 28 03 15
Fax: +46 8 96 73 95
sales@fengco.se
www.fengco.se

Taiwan
Scientific Formosa Incorporation
11th Fl. 354 Fu-Hsing N. Road
Taipei, Taiwan, R.O.C.
Tel.: +886 2 2505 05 25
Fax: +886 2 2503 16 80
info@sciformosa.com.tw
www.sciformosa.com.tw

Headquarters in Germany
dSPACE GmbH
Technologiepark 25
33100 Paderborn
Tel.: +49 5251 1638-0
Fax: +49 5251 66529
info@dspace.de

USA and Canada
dSPACE Inc.
50131 Pontiac Trail
Wixom, MI 48393-2020
Tel.: +1 248 567 1300
Fax: +1 248 567 0130
info@dspaceinc.com

Japan
dSPACE Japan K.K.
West Tower 9F
Yokohama Business Park
134 Godo-cho · Hodogaya-ku
Yokohama-shi
Kanagawa-ken 240-0005
Tel.: +81 45 338 3361
Fax: +81 45 338 3362
info@dspace.jp

France
dSPACE Sarl
Parc Burospace · Bâtiment 20
Route de la Plaine de Gisy
91573 Bièvres Cedex
Tel.: +33 1 6935 5060
Fax: +33 1 6935 5061
info@dspace.fr

United Kingdom
dSPACE Ltd.
Unit B7 · Beech House
Melbourn Science Park
Melbourn
Hertfordshire
SG8 6HB
Tel.: +44 1763 269 020
Fax: +44 1763 269 021
info@dspace.ltd.uk

dSPACE

www.dspace.com