TecDay:
Comfort development for the new C-Class

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Superlative ride comfort based on Mercedes Codes and digital prototypes

Sindelfingen – Mercedes-Benz will launch the new C-Class – a unique synthesis of superlative comfort and driving pleasure in this market segment – in spring 2007. This decisive edge comes courtesy of several years of experience, precise Mercedes Codes for comfort and a new development process which the Stuttgart-based manufacturer has implemented for the very first time: digital prototyping. Computer simulations enabled the engineers to define, test and refine the saloon's major characteristics at a very early stage of development, meaning that even the first ready-to-drive prototypes and pre-production models displayed a high level of maturity. Digital prototyping allowed the Mercedes engineers to make tremendous progress, especially in terms of ride comfort, quiet running, effective climate control and chassis tuning. This process is largely responsible for two of the key characteristics of the new C-Class – driving enjoyment and agility – both of which are of the usual high Mercedes standard.

The new C-Class is the world's first production vehicle to be designed and developed based on a digital prototype (DPT). In this process, Mercedes-Benz bundles together all of its calculation methods, using around 2130 gigabytes of data to create a completely virtual car. Computer simulation was used to develop and test the crash-safety and occupant-protection systems for the new C-Class as well as the car's NVH (noise, vibration and harshness), durability, energy management, climate control and aerodynamics. The Sindelfingen engineers use one of the world's largest IT networks for many of these calculations.

The new DPT process helped to save time and solve trade-offs at an early stage as well as permitting computer testing of the entire saloon concept. This environment created the ideal conditions for the subsequent field-development and road-testing phase, involving 280 real prototypes, which began in the summer of 2003. By the time full production gets underway, the new C-Class will have clocked up a

total of over 24 million test kilometres world-wide, making this the largest test programme in the Stuttgart manufacturer's history.

Computer- and test rig-based test drives with the digital prototype

Comfort and handling were focal points of the development work. The Mercedes experts put the digital prototype through its paces on virtual urban and country roads as well as motorways in order to define the ride comfort at an early stage. This test volume is equivalent to around 2000 individual drives in reality. To tune the handling characteristics, the digital prototype completed more than 1500 computer-based obstacle-avoidance tests, slaloms and braking manoeuvres – many of them in real-time simulations.

In addition the new development process allowed the saloon's handling characteristics to be experienced subjectively. State-of-the-art test rigs such as the Ride Simulator were programmed with the C-Class data and the road surfaces of real test routes so that the engineers were able to "drive" the new Mercedes model on the test rig very early on in the project. Although the Ride Simulator simulates the saloon's handling characteristics digitally, it does so realistically.

Over 6000 pages of Mercedes Codes for defining hallmark Mercedes features

Development of the new C-Class was based on a main specifications book containing around 360 pages, This book describes the saloon's technology right down to the last detail and specifies strict targets – called Mercedes Codes – for important characteristics. Some 150 main criteria, along with thousands of individual targets compiled in 250 component specification books with a total of over 6000 pages, relate solely to the topic of comfort – a key aspect of the C-Class alongside safety, reliability, quality and agility.

The Mercedes Codes for comfort reflect the many decades of experience and the vast pool of know-how that the Stuttgart manufacturer has acquired in this area of passenger-car development. As well as defining technical requirements, the Codes take into account scientific analyses performed at DaimlerChrysler's Customer

Research Centre, looking at how motorists perceive comfort subjectively. It was therefore possible to bring technical features into line with sensory perception – a key requirement for ensuring the classic Mercedes driving experience.

Comfort development requires profound and detailed knowledge of how irritating noise and vibration is caused and transferred. Mercedes-Benz analyses a total of around 60 different phenomena in these areas, including the typical lifting, pitching and rolling of the car body as well as many largely unfamiliar phenomena which can mar the comfort experience, such as quivering, micro-quivering, wobble, shimmy, grumble and whine, to name but a few technical terms.

Low-vibration body for outstanding long-distance comfort

The aim of the C-Class development engineers was to combine superlative ride comfort with sporty agility. A quick glance at the saloon's code book reveals that this goal was achieved: the C-Class easily achieves the stringent Mercedes targets and thus sets the benchmark for long-distance comfort in its market segment. In the case of micro-quivering – the term experts use to describe the comfort characteristics on slightly uneven roads – the readings for the new C-Class undercut the maximum limits specified by Mercedes by as much as 15 percent.

The saloon is equally adept at compensating for the typical body shudder caused by uneven road surfaces, which can be transferred into the interior of the car via the wheel carriers, springs, shock absorbers and mounts. At 140 km/h, the driver of the C-Class feels almost none of this shudder: the figure achieved by the C-Class – less than 0.3 m/s^2 – is around 40 percent lower than the already strict limit imposed in the specifications book.

Key factors which contribute to this high level of ride comfort include an intelligently designed bodyshell which is 13 percent more torsionally stiff than that of the outgoing model, newly developed seats and a standard-fit damping system which adjusts the shock-absorber forces in accordance with the driving style.

Quiet engines and a pleasantly calm interior

Equally impressive progress has been made in the field of acoustic comfort, which the Mercedes engineers have improved by implementing a series of measures, including even more effective acoustic insulation of the interior, sound absorbers in the body cavities and a sophisticated door-sealing concept. The engines and exhaust systems have also been enhanced with respect to comfort. By way of example, a new injection system audibly reduces the combustion noise in the four-cylinder diesel powerplants. The difference can even be heard when the engine is idling. Here the noise level of the four-cylinder CDI engines easily beats the Mercedes target of 62 decibels.

At higher speeds, the body's excellent aeroacoustics play an important part in ensuring a high level of ride comfort. Wind noise, often perceived as annoying high-frequency hissing in the interior, is practically inaudible when travelling on board the new C-Class.

Based on meticulously calculated empirical values and with the help of the latest development processes, the Mercedes-Benz C-Class opens up a clear lead – taking the concept of superlative comfort and agility to previously unscaled heights.

Contact
Norbert Giesen, tel. +49 711 17-76422 norbert.giesen@daimlerchrysler.com

Website
Further news about DaimlerChrysler is available by visiting:
www.media.daimlerchrysler.com

The Mercedes Codes - comfort based on experience

- **360-page specifications book containing Mercedes Codes for comfort**
- **Targets and know-how the result of years of development work**
- **C-Class offers highest level of ride comfort in its market segment**
- **Unique synthesis of technology and emotion**
- **Innovations in body and chassis technology**

Comfort is a multi-facetted topic. It is perceived, experienced and assessed with all the senses. This fact alone highlights the complexity behind the term "comfort". Although objective measured variables can indicate the existence of typical comfort aspects – such as good climate, restful calm, balanced suspension or pleasant feel – none of these variables reflect subjective (i.e. human) perception. And this is what really determines how we experience comfort.

In other words, developing comfort means bringing technical features into line with sensory perception; adapting technology so that it offers people a positive experience in every respect.

Achieving this objective requires one thing above all: knowledge based on experience. In this area of automotive development, Mercedes-Benz has far more experience than any other passenger car manufacturer. Alongside safety, reliability, quality and value retention, Mercedes models have always delivered unsurpassed long-distance comfort.

Based on their many years of research and development work, the Mercedes engineers know how to avoid discomfort and how to achieve comfortableness for car occupants. They also know what appeals to car drivers on an emotional level, how they sense comfort and to what extent they perceive comfort consciously or expect comfort subconsciously. This is where technology and emotion come together. This is where knowledge and experience combine to produce an outstanding result: hallmark Mercedes comfort.

The Mercedes engineers compile their know-how about this and other characteristic features of Mercedes cars in a specifications book – a meticulously acquired and strictly monitored pool of knowledge based on many years of evolution in automotive technology, which gets bigger and, therefore, more valuable, with each passing year and each new model series.

At the start of each development project, the specifications book is rewritten and adapted in line with the model series in question. The book for the new C-Class contains around 360 pages. And 150 of the "Mercedes Codes" defined by targets, measuring instructions and descriptions relate to the topic of comfort alone. They are explained in even more detail in 250 component-specification books comprising a total of around 6000 pages. The aim was to achieve a new dimension in ride comfort in this vehicle category but without neglecting other equally typical Mercedes hallmarks such as safety, agility and quality.

Vibration and noise: from shimmy to grumble

The Mercedes experts describe one of the main aspects of ride comfort with just three letters: NVH stands for noise, vibration and harshness. From the concept phase up until the start of production, NVH was an integral part of every development process. Engineers in various disciplines worked together to create a new comfort experience for the C-Class occupants.

NVH is development work based on experience. In order to achieve hallmark Mercedes comfort, the first job is to pinpoint the type of vibration and noise which can be sensed whilst driving and how this vibration and noise is transferred to the car interior or the ears of the occupants. Hence the Mercedes portfolio of comfort-related vibration and noise comprises around 60 different phenomena, all of which were meticulously analysed, assessed and, if necessary, eliminated whilst the C-Class was being developed.

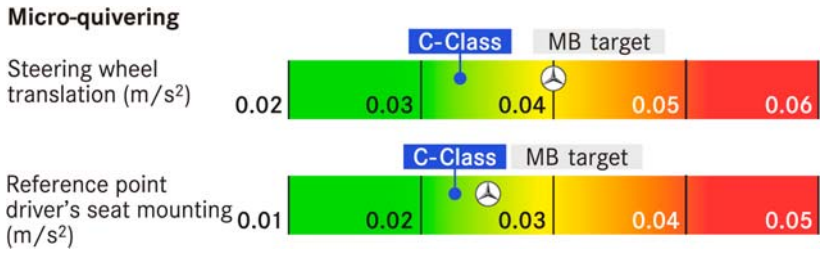
These audible and perceptible occurrences include the typical lifting, pitching and rolling of the car body as well as many largely unfamiliar phenomena which can be latently present during driving and thus persistently mar the comfort

experience: quivering, micro-quivering, wobble, shimmy, grumble and whine, to name but a few NVH terms.

Mercedes-Benz has defined precise targets for each of these 60 or so phenomena in the C-Class specifications book. None of these targets must be exceeded. Viewed as a whole, they essentially form the Mercedes Code for comfort.

A glance at the contents of the Code Book reveals just how much attention the Sindelfingen engineers pay to the topic of comfort and the extent of their achievements with the new C-Class:

- **Micro-quivering:** this is the term Mercedes experts use to describe the vehicle comfort on slightly uneven roads. The chassis should be capable of largely compensating for this unevenness so that the occupants can enjoy a smooth ride – a prerequisite for excellent long-distance comfort. The new C-Class meets these high Mercedes standards and beats the already impressive target achieved by the outgoing model by around 15 percent.



- **Trembling:** uneven roads cause the wheels and axles of a car to vibrate (15 to 40 Hertz). These vibrations are transferred to the car body via the wheel carriers, the springs, the shock absorbers and the mounts. The car occupants feel this phenomenon through vibrations on the steering wheel, the seat cushions and the seat backrests. Since continuous trembling movements of this kind mar the driving experience, Mercedes-Benz specifies strict limits for various road speeds. For instance, the steering wheel's rotational acceleration should not exceed 0.5 m/s² at 140 km/h, while the maximum permitted limit on the driver's seat mount is 0.35 m/s². The new C-Class more than meets the

requirements of these Mercedes Codes and achieves figures of less than 0.3 and 0.2 m/s² respectively.

Body engineering: torsional stiffness improved by 13 percent

The intelligently designed bodyshell meets important criteria with respect to the excellent ride comfort which distinguishes the new C-Class from other saloons in this market segment. The static torsional stiffness – an important indicator of the body's vibration response – has been improved by around 13 percent compared to the outgoing model. The Sindelfingen engineers paid particular attention to the connecting points between the chassis and body, which have to withstand extremely high loads. They were strengthened in specific areas to prevent the vibrations caused by the road from being transferred to the body so as not to mar the driving experience.

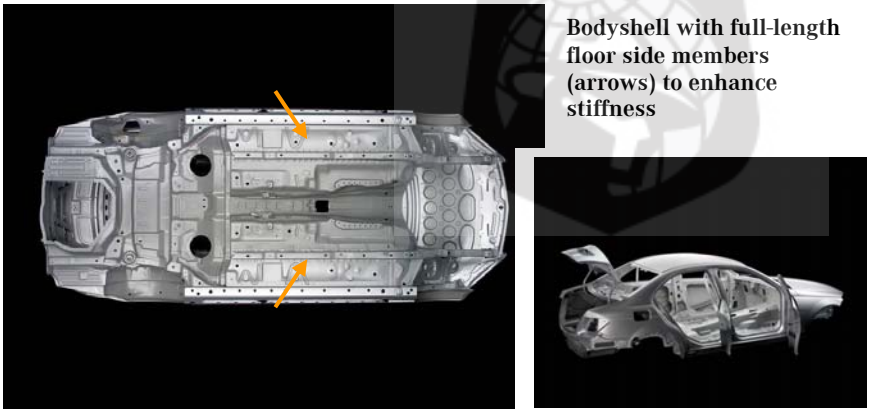
In addition, the stiffness at the points between the powertrain and the body where load is transferred was increased by up to 17 percent – a measure which benefits the saloon's agile handling as well as its vibrational comfort.

When selecting the materials for the body, preference was given to high-strength steel alloys because they minimise weight whilst maximising strength and, therefore, safety. Around 70 percent of all the bodyshell panels for the new C-Class are made using these steel grades – a new record in passenger-car development.

Particularly worthy of mention are the sophisticated, ultra-high-strength steel panels that have only been developed in recent years. Their tensile strength is

three to four times higher than that of conventional steel grades, thus making them indispensable for meeting the strict Mercedes requirements in terms of durability, safety and vibration response. These high-tech, ultra-high-strength alloys account for around 20 percent of the weight of the new C-Class bodyshell.

New features which are crucial with respect to both occupant safety and body stiffness include the two full-length floor side members which have been further reinforced with additional sections on their insides. At the front end they adjoin the longitudinal members, while at the rear end they reach as far as the cross member below the rear seats and thus stabilise the entire floor structure. This extra stabilisation substantially enhances the body's vibration response.

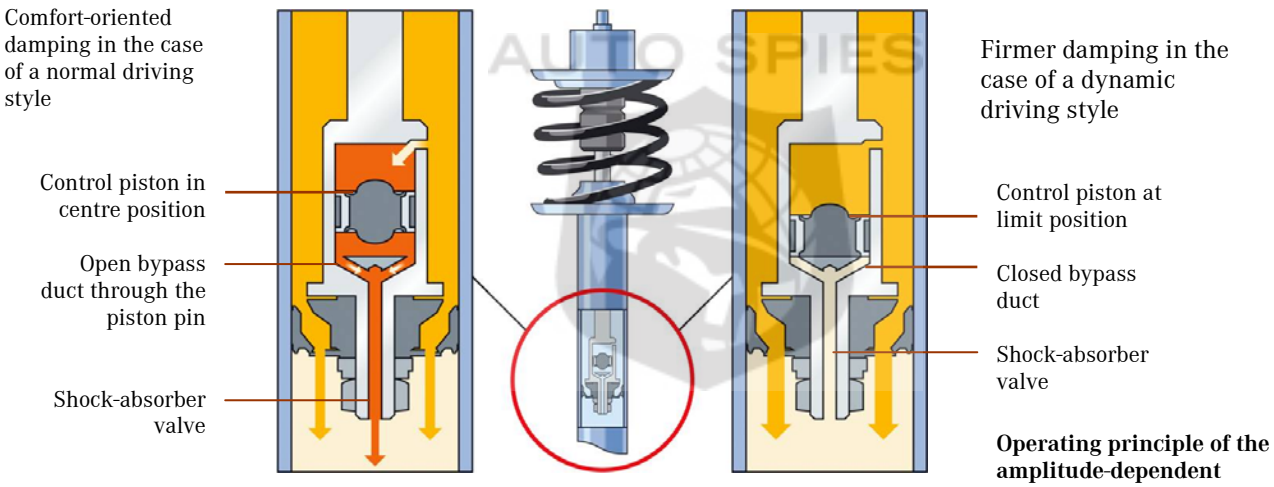


Bodyshell with full-length floor side members (arrows) to enhance stiffness

Chassis technology: damping force adjusted in line with driving style

Newly developed chassis technology provides the ideal foundation for the C-Class saloon's agile and comfort-oriented handling characteristics. Perhaps the most important element is the amplitude-dependent damping system which the C-Class includes as standard. With a normal driving style and low excitation of the shock absorbers, the damping forces are reduced automatically, which has a noticeably positive effect on the saloon's ride comfort without impairing driving safety. However, if the shock-absorber excitation is greater – for example when cornering at speed or when performing evasive manoeuvres – the maximum damping force is applied in order to ensure effective stabilisation of the car.

This technology works by purely hydromechanical means without the need for complex sensors and electronics. It is essentially based on a bypass duct in the shock absorber's piston pin and a control piston which moves in a separate oil chamber. When the shock-absorber bounce is low, the control piston moves oil through the bypass duct so that a much lower damping force is produced at the shock-absorber valve. The result is "softer" shock-absorber characteristics and, therefore, a high level of ride comfort.



Operating principle of the amplitude-dependent damping system

If the excitation of the shock absorber is greater, the control piston moves to its limit position and oil ceases flowing through the bypass duct. As a result, the full damping force is available.

Seats: newly developed foam upholstery with two-zone comfort

The Mercedes engineering team also paid particular attention to the seats, since they can be equally crucial when it comes to long-distance comfort. The result is newly developed front seats which offer further advantages in terms of pressure distribution and lateral support. This was achieved by developing seat contours with more pronounced side bolsters and by using two-zone upholstery: in the outer zones – particularly in the side-bolster areas – the foam is harder so as to provide good lateral support, while the inner zone of the seat surface is softer. In addition, the foam upholstery used for the seat surfaces is around five percent thicker than in the outgoing model.

In this way, the Mercedes specialists are able to achieve an even pressure distribution and avoid pressure peaks, especially below the ischial-tuber area, which can cause a feeling of unpleasantness on long drives.

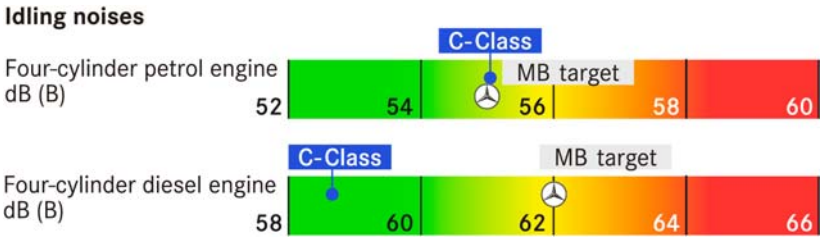
The foam upholstery is housed in seat squabs with integral suspension. A frame made partially from high-strength steel forms the solid basis for the front seats. The front seat backrests consist of steel frames and foam elements whose contours, like the seat surfaces, provide even better lateral support. The volume of the foam backrest has been increased by around five percent compared to the seat in the previous C-Class. A standard-fit lumbar support allows the driver to adjust the backrest contours to suit the anatomy of his or her back and so relieve muscle stress – a further factor which enhances long-distance comfort.

Low noise levels: audible progress at idle speed and when driving fast

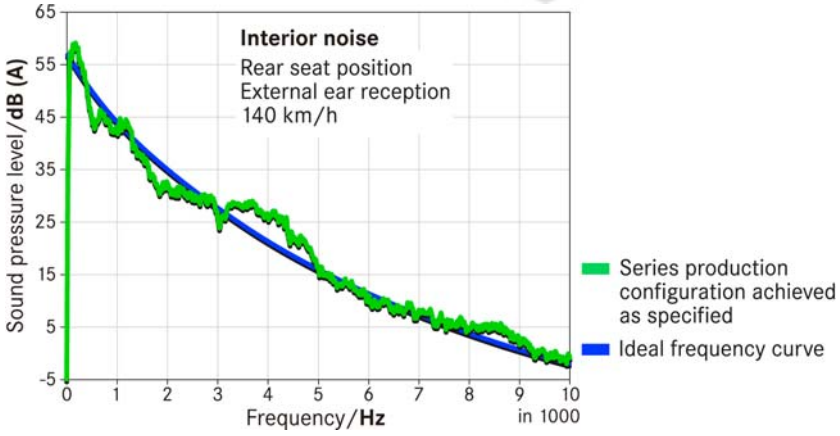
As well as stringent vibration limits, Mercedes-Benz specifies strict noise limits, again based on several years of experience. These Mercedes Codes take into account all driving situations and conditions – from idling speed to top speed.

- **Idling noise and driving noise:** this audible comfort-related phenomenon involves the transfer of engine noise to the interior via the engine mounts, integral support frame and body. Mercedes-Benz specifies specific driving-

noise and idling-noise limits in the form of Mercedes Codes for every engine variant. At idling speed, the new C-Class easily meets these targets and thus sets new comfort standards in this discipline.



- **Hiss:** when travelling at high speed, the air flowing around the car body can cause unpleasant, mainly high-frequency wind noise which reaches the interior via the body, the windows, the doors and the sunroof. The Mercedes experts have defined targets which limit the sound pressure level at different frequencies. The sound pressure level in the new C-Class follows this "ideal line" and therefore meets stringent Mercedes requirements regarding acoustic comfort at high speed.



Sound insulation: thicker carpet and specific firewall insulation

The outstandingly low noise levels inside the new C-Class are the result of meticulous work carried out on test rigs and following test drives. The Sindelfingen experts call this work "NVH tuning". And it makes a clearly audible difference. For instance, they developed additional insulation measures which damp vibrations and absorb sound even more effectively than was the case in the outgoing model. One example of this is the carpet in the saloon's interior, whose insulation characteristics have been intelligently enhanced: now the carpet is combined with a foam which is lined on its underside to create a spring/mass system. Not only has the thickness of foam been doubled compared to the outgoing model, the material also covers a larger section of the floor panel and can therefore absorb disturbing noises up to 20 percent more efficiently. The thicker foam, coupled with the foam's excellent insulation characteristics, made it possible to reduce the weight of the heavy layer by up to 50 percent – one of several aspects which contribute to the lightweight design.

The extremely low noise levels are also attributable to the "soundproof" dashboard, whose front section is fully insulated so that no disturbing engine noise reaches the interior, and to the enhanced soundproofing material used for the firewall. The Mercedes engineers used computer simulations to optimise the firewall insulation. Plus they defined the thickness of the sound-absorbing resin foam with pinpoint accuracy, based on the level of noise emmission.

Bodyshell cavities are filled with special foam absorbers which absorb disturbing noise. These elements are first mounted on special support plates and then firmly attached to the body. In the dry zones of the paintshop, the soundproofing materials expand of their own accord and completely fill the cavities. Each of the body's two sidewalls conceals nine of these foam absorbers.

The Mercedes engineers responsible for developing the new C-Class combated the wind noise caused by air flowing around the body and its attachments or by vibration excitation of the panel surfaces by making the bodyshell stiffer using full-length floor side members and reinforced outer skin surfaces. They also

employed a new door-sealing concept: the doors of the C-Class now have two or, in crucial areas, even three orbital sealing levels.

Climate comfort: heating and cooling output boosted by up to 15 percent

When it comes to effective climate control, too, the new C-Class outperforms its predecessor by a clear margin. The Sindelfingen engineers have developed two new air conditioning systems. One of them – THERMATIC – is specified as standard for the new saloon. Meanwhile the optionally available THERMOTRONIC system incorporates sophisticated technology which allows three-zone climate control in the car interior – a first in this vehicle category.

Both air conditioning systems have received a boost in heating and cooling output. The heating output has been increased by around ten percent to eleven kilowatts, equivalent to the power of the central heating system in a modern family house. An air conditioning unit whose output is 10 to 15 percent higher than its counterpart in the outgoing model ensures rapid cooling of the interior.

Preventing draughts is a further important aspect of comfort; this is why the Mercedes engineers further enlarged the ventilation outlet opening areas, thus reducing the air flow speed and, therefore, the risk of irritating draughts. A total of 16 outlets effectively and evenly ventilate the interior. With the exception of the defroster outlets below the front windscreen and the outlets in the footwells, all of the ventilation outlets allow infinitely variable adjustment of the air quantity. The THERMOTRONIC system also includes an automatically controlled, upwards-pointing diffuser outlet on the dashboard, which ensures indirect and, therefore, draught-free ventilation.

Sophisticated sensor systems see to it that the ideal temperatures desired by the occupants are kept constant. For instance, two sensors measure the interior temperature and provide the system with even more precise data so that it can react more quickly to temperature fluctuations. The sensors are located in the overhead control panel and next to the electronic ignition lock. In addition, four sensors monitor the temperature of the air flowing out of the ventilation outlets,

enabling a continuous comparison between the desired and actual temperatures. A further sensor records the intensity and direction of the sun's rays. These data allow the automatic climate control system to control the air quantity and temperature based on the driving situation or weather conditions, thus making sure that the C-Class occupants enjoy a consistently high level of climate comfort.

Digital prototype – calculating the way ahead

- **Complete digital depiction of new car models**
- **Early project verification thanks to simulation of all functions**
- **Comfort and handling can be experienced subjectively on test rigs**
- **C-Class marks premiere of new development process**

Prototypes are precious commodities in the automotive business – one-offs that are constructed by hand over a period of months but which only have a short yet action-filled life. Prototypes travel incognito, their true identity hidden by ugly matt black camouflage. It's all very hush-hush.

But prototypes are essential tools in the car developer's armoury. They are the only means of "teaching" future models to drive; and the only way of testing and further developing new technologies on board under realistic conditions at an early stage of development. Mercedes-Benz produced a total of 280 prototypes for the new C-Class. These were then sent around the world for rigorous testing, during which they clocked up millions of test kilometres.

But that is not all: in the case of the new C-Class, the word prototype has a double meaning for the first time. This is because, long before the first heavily camouflaged versions of the new saloon hit the road, a different kind of prototype had already successfully negotiated a series of tests. These virtual prototypes, many details of which depicted the later production model, allowed the car's characteristics to be experienced at an early stage of development. Mercedes experts talk about digital prototyping (DPT), by which they mean a new kind of development process. The new C-Class is the world's first production vehicle to be developed using this leading-edge method.

The digital prototypes incorporate the Sindelfingen experts' vast know-how in the field of computer simulation and calculation. Since the early eighties, when the first high-powered computers allowed more or less detailed crash simulations, rapid strides forward have been made on both the hardware and the software

front. Whereas in 1989 crash calculations were still based on models which depicted the vehicle using around 26,000 elements, the new C-Class was split up into around 1.9 million elements, therefore allowing a far more precise and detailed deformation analysis. For such impact calculations, during which computers complete an almost unimaginable stream of up to 320,000 million operations, Mercedes-Benz uses one of the world's largest IT networks: over 1500 processors were involved in the development of the C-Class safety systems; and the Mercedes saloon completed around 5500 computer-aided crash tests.

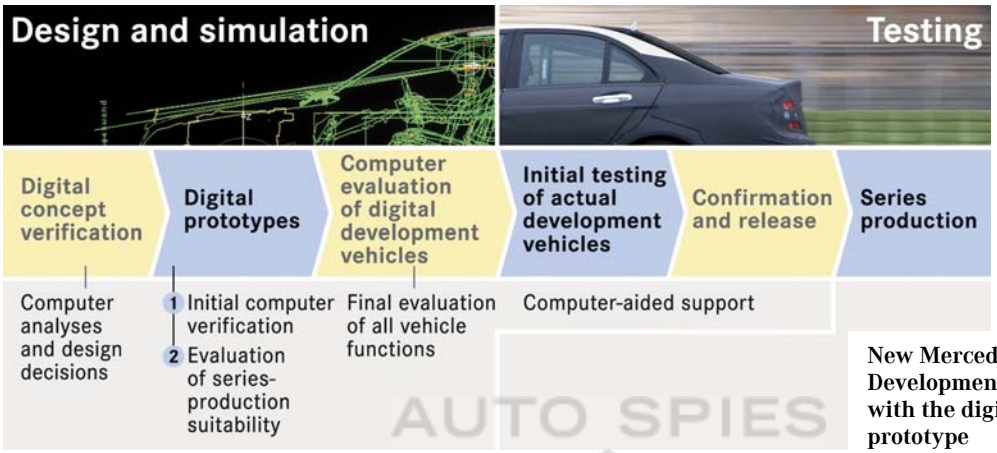
This shows just what can be achieved using today's sophisticated simulation and calculation processes. They are not just used to optimise new-car safety, they now also assist the engineers with aerodynamic analyses, interior-climate simulations, durability analyses and engine development.

The digital prototype sees Mercedes-Benz bundling together all of its simulation methods for the very first time in order to produce an entirely virtual car.

Of course, the digital prototype does not replace the real prototypes and test cars which are still tested extensively in the field. However, the digital prototype can help to optimise the first ready-to-drive models. These models are therefore much closer to their subsequent production counterparts. Whereas in previous years the first prototypes were essentially based on the vast experience of the Mercedes engineers, with virtually no computer data to verify the validity of the concept as a whole, experts today work on a much more solid basis, even in the very early stages of development, thanks to the digital prototype.

Digital and real: passenger car development in two phases

The Mercedes-Benz Development System (MDS) is now therefore split into two main phases: concept development and calculation with the digital prototype in phase 1 and field testing with real prototypes in phase 2, during which simulation processes continue to be used for assistance and verification purposes.



New Mercedes Development System with the digital prototype

All the data for the new model – from the dimensional concept to the shock-absorber characteristics – are incorporated into the digital prototype. These data are then conditioned. Once all the calculation models have been prepared, the status of the DPT is equivalent to that of an actual four-wheel prototype that is ready to drive. The virtual test drive can commence.

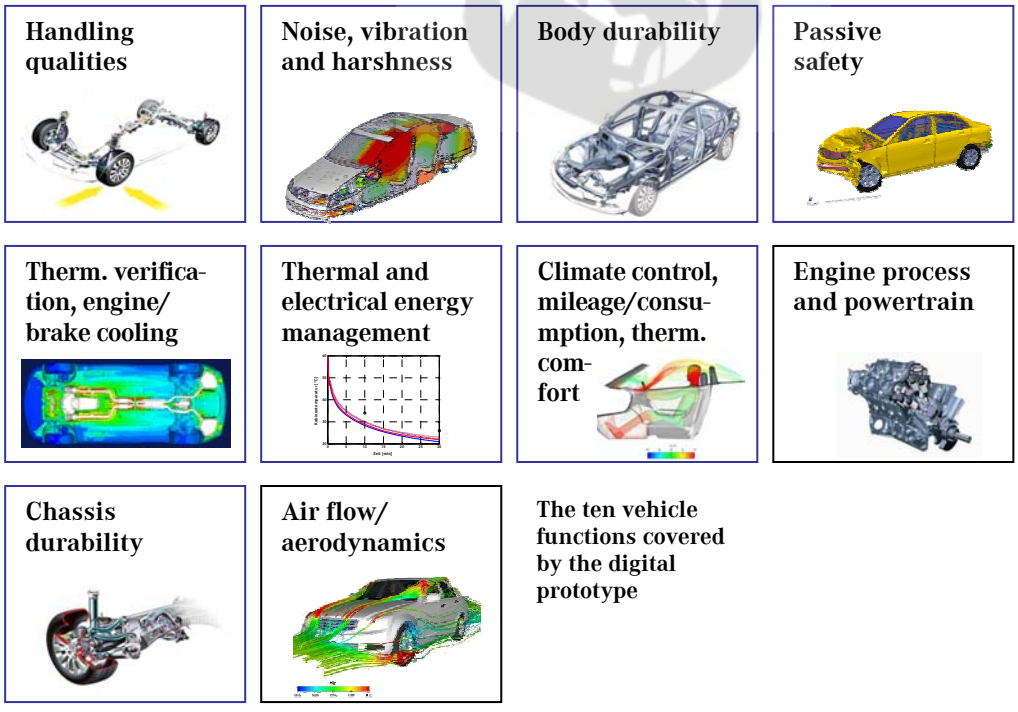
This involves tuning and defining right down to the last detail in order to verify the validity of the entire concept for the new model by way of calculation, solve trade-offs at an early stage and create the ideal conditions for the subsequent field-development and road-testing phase.

Furthermore, all model and engine variants can be tested digitally. Once the basic data for the new model have been compiled, changes or departures from the norm can be implemented by simply entering new data. This is a further advantage of the digital prototype: no workshops or production facilities are needed to build or convert test cars – it's all done by DPT experts with little more than a few clicks of a mouse.

Digital depiction: ten functions covering the key vehicle features

Of course, the digital prototype of the new C-Class was not tested as an entire vehicle using simulation techniques. This would scarcely be possible due to the vast data quantity of up to 2130 gigabytes and the colossal computing power required – nor would it be appropriate. Instead, the Mercedes engineers divided the car into the key functions which depict its fundamental characteristics.

These include crash safety, occupant protection, quiet running, vibrational comfort, body durability, ride comfort, handling characteristics, engine characteristics and several other aspects. The Sindelfingen experts use the digital prototype to depict a total of ten vehicle functions which cover the key features of the car.



The ten vehicle functions covered by the digital prototype

In the case of the new C-Class, this enabled the calculation and realistic depiction of crash safety, body aerodynamics, engine cooling, brake cooling and energy

management on board the future Mercedes model at a very early stage of development.

Sporty or comfortable: virtual road test with the digital prototype

Digital vehicle development is especially important when it comes to defining the handling characteristics. This involves a familiar trade-off between comfort and agility; however, solving this trade-off is important as this is what gives the new Mercedes model its unique character.

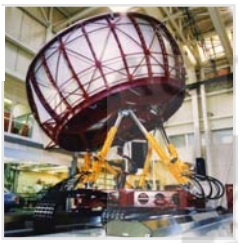
In this domain, the new DPT process served impressive notice of its potential. Before the first real C-Class test cars had been produced, the digital prototype had already covered around 1500 kilometres on virtual urban and country roads as well as motorways in order to define the ride comfort at an early stage. This virtual test volume is equivalent to around 2000 individual drives in reality. One of the focal points of this work involved assessing the vibration response between four and eight Hertz – a frequency range which can easily be perceived by humans. The acceleration data for these test drives were depicted realistically by computer; appropriate processing of these values made it possible to give an indication of their subjective effect.

In addition, the Mercedes experts completed more than 1500 typical driving manoeuvres in the virtual world – many of them in real-time simulations – in order to harmonise the handling characteristics. This series of tests included various standardised obstacle-avoidance tests, slaloms and braking on bends.

However, the work on the computer screen was only the first phase of comfort and handling harmonisation; the digital prototype also allowed the handling qualities of the C-Class to be experienced subjectively – on highly sophisticated test rigs controlled using detailed DPT data. The new process thus gave the Mercedes engineers a clear advantage in terms of both time and quality; the new C-Class was able to complete its first test aimed at harmonising comfort and handling several months before the field-testing phase began.

One of the test rigs that can use data to "drive" the digital prototype is the Driving Simulator at the DaimlerChrysler research facility in Berlin. Here the Mercedes engineers assessed the cornering capabilities, steering characteristics and braking performance of the C-Class and, at the end of the test series, defined the data for the shock absorber characteristics, the spring rates and the steering characteristics, for example, all of which laid solid foundations for the subsequent field-testing phase.

Driving simulator in Berlin



Test rigs for subjective assessment of comfort and handling based on digital-prototype data

Ride Simulator in Sindelfingen

The comfort tests completed by the new C-Class before any ready-to-drive prototypes had even been produced are equally impressive and representative. In this case, the Mercedes experts used a new type of Ride Simulator which was programmed with the data for real test-track surfaces and the necessary C-Class chassis and function data. Thanks to the combination of sophisticated multibody simulations and state-of-the-art test rig technology, the system enabled the ride comfort to be experienced at an early stage. A driver and a front passenger sat in the test rig's two seats and proceeded to drive the new saloon. This was a purely digital but highly realistic exercise.

"TIM": a virtual driver with almost every body function

Digital prototyping also gave the engineers an insight into the virtual interior of the new C-Class, enabling them to check how the air conditioning system performed. For example, they were able to verify whether the occupants always had warm feet when driving in winter.

This climate-control simulation is one of the most complex calculation processes. Because the vehicle speed, temperature, level of sunlight and humidity change constantly when on the move, the computer program has to react just as quickly and flexibly as a car's air conditioning system if the occupants are to experience a consistently high level of comfort. After all, people only feel really comfortable if their climatic surroundings remain pleasantly constant.

TIM – the German acronym for "thermophysiological occupant model" – makes this possible. TIM is an instrument used to calculate and optimise climate comfort for future vehicles. It enabled the engineers to ascertain several features of the C-Class at a very early stage of development, for instance the desired heating and air conditioning system output, the number of ventilation outlets required and the size of outlet needed to achieve typical Mercedes climate comfort.

TIM is the result of many years of work by DaimlerChrysler researchers in the field of human thermal comfort levels. A large number of male and female drivers provided the basic data for the so-called "equivalence temperature" which corresponds to the temperature "felt" by car occupants and enables the actual, perceived climate comfort to be defined for each part of the body. The "TIM" computer model simulates most of the human body in a total of 14 areas, also taking into account the blood circulation and heat generation. The result is a virtual but entirely representative car occupant who is sent to all the climatic zones of the world by computer and supplies Mercedes engineers with a mass of data. These are intended to answer only one question: does the occupant feel comfortable?

TIM also put in test drives of many hours duration under the most varied driving and weather conditions in the digital prototype of the new C-Class. In addition, TIM was linked to other computer programs which for example divided the interior into around 7.8 million spatial units and measured the air flow, temperature and other comfort parameters at each of these points.

On-screen readouts enabled the engineers to establish when the respective feel-good temperatures were reached and whether TIM indicated the right comfort level. If required, a few keystrokes at the computer were enough to adjust the climate-control system until the two virtual vehicle occupants began to transmit satisfactory data.

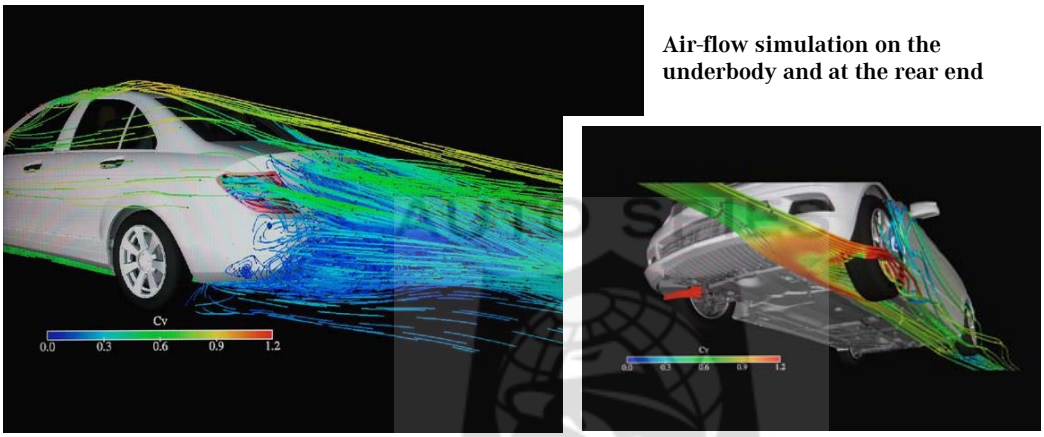
Three-dimensional simulation of temperature distribution and air flow

Something good in the wind: computer-simulated storm lasting 36 hours

For the aerodynamics engineers, work also began long before the first prototypes were ready to roll into action and took place in the model wind tunnel using the digital prototype. Based on the key exterior dimensions and the basic stylistic concept, the first 1:4 models of the new C-Class were produced and completed numerous tests in the wind tunnel, laying the groundwork for the new car's impressive aerodynamics. This experimental work was backed up by air flow simulations centred around Computational Fluid Dynamics – or CFD for short. This is the term experts use to describe the complex process involved in building up a simulation of air flow characteristics. State-of-the-art CFD software enables calculation and optimisation of the aerodynamic conditions under the bonnet, around the underbody and in specific areas of the car body. This allowed the Mercedes engineers to identify potential for further improvements at an early stage.

Working through these calculations is part of a process lasting several hours: in order to simulate the precise course of the air flow over and around individual areas of the car, such as the radiator grille or front apron, the powerful computer

has to chart a path through highly complicated differential equations with more than 30 million fluid elements. It works for 36 hours at a time in order to calculate a single speed and pressure field, which is then displayed on the screen in the form of colour animations.



Air-flow simulation on the underbody and at the rear end

Audible results: acoustic calculations in all driving situations

NVH is an automotive engineering term that stands for noise, vibration and harshness.

In this important domain, too, the digital prototype performs invaluable tasks. With the help of computer simulations, the NVH experts were able to stipulate their requirements at an early stage of the vehicle project and actively help to shape the new C-Class. One example of this was the development of the bodyshell. In this case, specific stiffening or bending of the panels helps to substantially reduce the amount of noise that reaches the interior. Previously this type of modification could only be made at a later stage and therefore incurred much greater expense.

The NVH calculation model depicts the complete vehicle with its bodyshell, doors, powertrain and axles. The computer can simulate practically any everyday situation: engine idling, driving on uneven roads, tyre imbalance or sudden acceleration. The resultant vibrations are transferred to the car body and are ultimately perceived as disturbing noise by the car's occupants. Calculation of

these vibrations requires a complex mathematical model which has to take into account the air inside the car as well as the various sources of vibration such as the engine, powertrain, axles and individual panel structures. After all, without air, the sound could not be heard.

During the virtual test drive, the computer depicts the sound pressure with a range of colours, thus enabling the experts to ascertain the percentage of the interior noise level attributable to specific sources of noise and at what points the sound radiation is at its greatest. The vibration and noise is assessed above all at those points where comfort is most important for the car occupants, for example at ear level, on the steering wheel and on the seats.

In summary, the development of the Mercedes-Benz C-Class has opened the door to a new, leading-edge development concept: the digital prototype improves processes, helps to save time, verifies the feasibility of projects at an early stage and ultimately gives new Mercedes models an even sharper competitive edge than before – in terms of both technology and quality.