TECHNICAL PERSPECTIVE

"Vehicle Dynamics Technologies to Provide Driving Pleasure" Round-Table Discussion

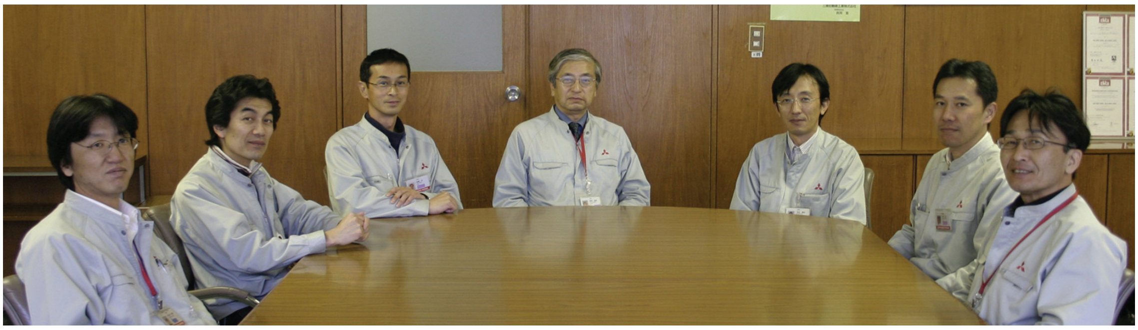
Abstract

Mitsubishi Motors' corporate philosophy is encapsulated in the following motto:

"We are committed to providing the utmost driving pleasure and safety for our valued customers and our community. On these commitments we will never compromise. This is the Mitsubishi Motors Way."

In this issue focusing on driving pleasure, we hear from the engineers in charge of developing the technologies for enhanced vehicle dynamics and 4WD systems, which provide the core support for driving pleasure.

Key words: *Driving Pleasure, Vehicle Dynamics, 4WD System*



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1. Introduction

Nishida: In recent years, we have seen remarkable progress in vehicle dynamics control technologies. These technologies have the possibilities of allowing drivers to operate a vehicle more safely and comfortably, even in difficult conditions or even if they are unskilled. As you know, Mitsubishi Motors Corporation (MMC) has adopted "utmost driving pleasure" as a key phrase expressing the driveability and roadability that is the fundamental attraction of our vehicles, aimed at producing exciting vehicles. These dynamic control technologies are incorporated in the LANCER EVOLUTION and other MMC vehicles and now support driving pleasure as well as "toughness and safety", which is another of our key phrases. On the other hand, vehicle systems that work on these control technologies do not necessarily meet the driver's expectation, sometimes leading to the driver feeling that this spoils the fun of driving the vehicle. This suggests that electronic control is not always welcome and there are areas where intrinsic performance of the vehicle reigns. I think that achieving an optimum combination of the two is an ultimate goal as we strive to offer driving pleasure to our customers. Needless to say, the application of latest testing and analysis technologies, extensive field trials, and stringent and accurate evaluation are all indispensable to achieving the goal.

With this in mind, it is worth reviewing to what point our vehicle manufacturing has advanced in the field of vehicle dynamics technology. Today, we have attending engineers who are involved in vehicle dynamics technology development, from the control technology, basic technology and testing and evaluation sections. Please share your thoughts with everyone freely, including any difficulties you experienced.

2. Chassis control technology

Nishida: In the 1980s, vehicles incorporating dynamics control technologies were launched at MMC. These included the antilock brake system (ABS), traction control system (TCL), four-wheel steering system (4WS), variable-characteristic shock absorbers, height control system on air suspended vehicles, roll angle reduction control, and stabilizer-bar on-off control. And also the electronic control of the steering reaction force was applied to the power steering system. Today, some of these are installed as standard, while others do not appear to be as popular as they once were.

Motoyama: The categories that went through the most fluctuations were the 4WS and so-called variable characteristics suspension technologies, including damping-force-switching shock absorbers, air suspension and hydraulic suspensions. They boomed in the late 1980s, but did not gain long-term popularity. In the 1990s, there were no significant developments in their application. Recently, variable characteristics suspension technologies have regained popularity, mostly in Europe, especially with shock absorbers that have the capability of continuously varying rather than switching damping force characteristics. The temporary decline they experienced earlier was due to the immaturity of the systems, in both the hardware and software. Another reason appears to be the immaturity of the envisioned goals of these systems.

Funo: As a specific case, the 4WS was a system that was developed to focus on a single area of a vehicle's functions. In fact, it displayed remarkable performance in this area, but the driver sometimes had difficulty in using it.

Motoyama: Back then, the Japanese automakers were ahead of competitors in other countries in developing these technologies. Both the manufacturers and the market here found value in something new that these systems offered. However, the market did not fully appreciate the functions that the new technologies offered, partly because most of them remained immature, even after being developed as products, due to a lack of refinement. For example, the market appreciated the 4WS for its ability to help in tight turns but not for its other abilities. Customers generally did not fully realize what benefits the 4WS could provide in what scenarios. Enhanced controllability and stability of a vehicle is difficult to feel as it is present or absent, depending on the driving environment, unlike significantly-improved ride comfort, which customers can easily perceive.

Sunouchi: A changing economic background has also influenced the popularity of these technologies. During the bubble years in Japan, people avidly looked for something technologically advanced and novel. After the bubble burst, people focused on value for money. Additional vehicle functions only work fully when the vehicle's performance itself is sound. European manufacturers continued refining the vehicle's basic performance over the years, and today, with a strong economic background, they have advanced to the point of adding value to the equipment. Japanese vehicle manufacturers, on the other hand, are now focusing on enhancing basic vehicle performance from the step they reached during the bubble years.

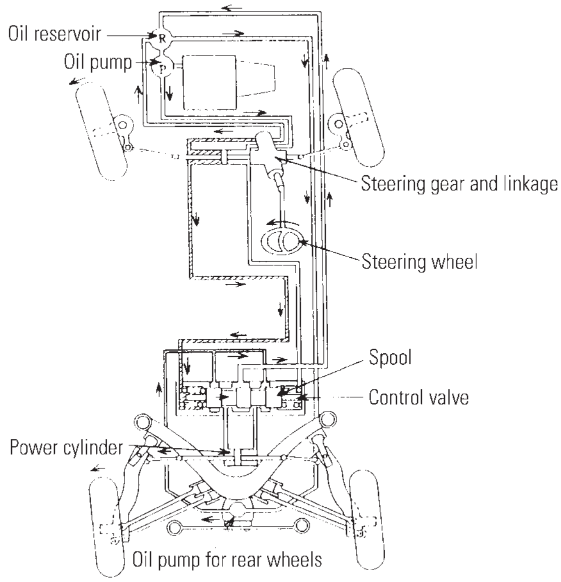

Fig. 1 4WS system (1987 GALANT VR4)

Sugimoto: The 4WS was not optimized for all speed ranges. Actually, the systems on the models for the European market were tuned to specifications different from Japanese market models.

Motoyama: Unpleasant feel, by its nature, is an unavoidable problem with the 4WS. A steering system completely devoid from such unpleasant feel is only the conventional front wheel steering system. It is also true that, no matter how well you familiarize yourself with the system, unpleasant feel will never become familiar and comfortable. To enjoy the full benefit of 4WS, maybe you must think, "the 4WS steers my car better than I can" just before driving the vehicle.

Funo: For a vehicle to be stable and controllable, the rear wheels must remain firmly in position. This is a basic rule. Therefore, there is inevitably argument regarding the 4WS as to whether a system that involves positional movement of the rear wheels can be said to be beneficial. Finding an optimal method of controlling its positional movement will pave the way to progress of the 4WS.

Motoyama: The 4WS has the potential to substantially expand the degree of freedom in toe control. Today's technology is still not that advanced. Perhaps, chassis control developments, assuming a 4WS-based platform, would drastically increase the possibilities.

Nishida: That is the active steering control working on the four wheels, including the front wheels. Front steering systems with variable gear ratio control have been introduced and some of them are combined with rear wheel steering control. MMC has also made its own technology relating with this control public. As with the steering system, development of the suspension system to enhance its variable characteristics by such means as controlling the damping force has become increasingly active today. Do you have any thoughts on this?

Motoyama: Technologies for selecting suspension characteristics were predominant in development in this field, but the trend has now shifted toward technologies for varying them continuously. The former technologies aimed at selecting the best characteristics, but actually selected characteristics might be neither better nor worse, while the latter aims at continually adjusting the system to optimum characteristics. Today, variable characteristics suspension systems are mostly employed on high-end luxury cars, but they will become popular with lower-priced vehicles. The key factor that decides whether the systems on high-end cars will evolve further will be the energy they consume. The weight of the additional control system for the drivetrain or steering system is greater than that of the braking system. The additional system for the suspension system is heavier than that of the drivetrain or steering system. As the weight increases, more power is consumed. An active steering system, for example, requires a maximum current of 10 A, approximately the same current as that of brake lamps, but an extra control system added to the suspension system weighs more and therefore consumes more current.

Sunouchi: Currently, air suspension systems are employed in some high-end sedans and sport utility vehicles (SUV). Hydraulically operated fully active suspensions were used in the past, but what we have today is classified as a semi-active type of suspension.

Motoyama: Hydraulic systems consume sufficient power to change the result of emissions test cycle driving. In this sense, electric active suspensions will be more feasible than hydraulic systems. Electric systems allow energy to be regenerated. Another merit is a much larger range of control.

Nishida: The conversion of various chassis systems into electrically operated systems is now advancing. The most important of these is electric power steering (EPS).

Sunouchi: EPS has had a issue in its steering feel. However, it can now give almost the same level of feeling as a hydraulic system. Nevertheless, friction and motor inertia remain an EPS challenge to be addressed. Besides the hardware, the approach may include enhancing the software.

Funo: EPS control technology may have the potential to give the driver a sporty feel.

Motoyama: The increased worm gear friction with the EPS is caused by road surface inputs. It is possible to solve this problem by developing the control technology, but this requires tremendous skill. Even with the best EPS today, the steering feel it provides is not as good as that with the best hydraulic power steering system in particular aspects.

Nishida: The EPS reduces fuel consumption. How about its contribution to the vehicle's dynamic performance?

Motoyama: We are going to expand the application of the stability control and brake-related control systems under the key theme of safety. The systems that follow these will be steering-related control systems because they have the potential to offer a high degree of freedom. Of course, one option is a system that combines these. The largest benefit of the EPS is a high degree of freedom of control. Its control is so free that we can even generate steering torque in the opposite direction to that of the driver's input.

Sunouchi: The EPS contributes less to the reduction of fuel consumption on larger vehicles. For these vehicles, the EPS will find its application in added functions, such as lane keeping and parking-assist systems, to assist the driver rather than to reduce the fuel consumption. The EPS will offer more potential in this area where the capabilities offered by hydraulic means have reached a limit.

Motoyama: I think another key point for success in the EPS is the embodiment of steering feel that is available only with an electric system control. The target is not something on a par with, but rather that exceeds hydraulic systems. Steering feel adds "flavor" to the vehicle.

Nishida: On a different topic, electric systems remind me of MMC's MiEV electric vehicle.

Funo: The MiEV has a low center of gravity, which means good stability in vehicle control. It sways little and only has a small load transfer in cornering, so you feel like the center of gravity is near the wheel axis. The location of the battery has been optimized, so the distribution of the vehicle mass is well controlled. Because the electric motor responds much better to accelerator operation than a mechanical engine, I think it is reasonable to design the response rather conservatively to prevent the driver from perceiving a surprising difference from gasoline engine vehicles when using the accelerator, although suppressing a good response is wasteful. What is important is a good-feeling response, low electricity consumption and problem-free running distances. The i MiEV runs really well. It is definitely a next-generation electric car.

3. Drivetrain control technology

Nishida: How about drivetrain control? Electronics have been applied to 4WD and other drivetrain controls to enhance the vehicle's dynamic performance.

Sawase: Electronic traction control technologies intended to enhance cornering performance, in addition to traction, are becoming the mainstream. Early electronic control applied to the 4WD system was an on-demand system that allowed high-speed on-road driving and distributed more torque to the rear wheels as lateral acceleration increased. At MMC, the first drivetrain control introduced as a means of enhancing the vehicle's dynamic performance was the system employed in the 1992 GALANT. This is the first fully-fledged system that controls the distribution of traction between the front and rear wheels by using the center differential full-time 4WD as a base system. Few people will know about this system because it was only produced in small volumes (laughter). Today, electronic control prevails in the on-demand 4WD system. Electronically controlled systems make up 60 to 70 % of all on-demand 4WD systems. Electronically controlled systems have become popular because not only do they add to vehicle dynamic performance, but they are also beneficial to weight reduction and fuel economy. The MMC’s system employed on the OUTLANDER has very simple control logic and is well refined. It has been well received in the market, with critics saying, “The system is pretty well matched to the vehicle. This must be the result of extensive test driving”. The OUTLANDER has good basic characteristics, and this gives the system positive effects.

Motoyama: What inspired us to start developing technology for lateral traction distribution was an idea that came from a simple question: “Our past traction control development was concerned with longitudinal traction distribution. What would happen if lateral torque distribution is controlled?” Only a short while after joining MMC, I started conducting simulations on this theme. I learned through simulation that changing the lateral traction could cause an enormous yaw moment to be generated and its generation could be completely stopped. I also learned that lateral traction control was very useful if it was combined with vehicle behavior feedback technology. I saw that this was also effective in enhancing traction. What mattered was not distribution but rather the shifting of traction. Zero traction remains zero traction even after distribution. We found that even under zero traction conditions, a vehicle’s dynamic performance could be drastically enhanced by turning one wheel faster than the other. That was in my third year with MMC, when I discussed that subject with Mr. Sawase. One week later, he appeared with a conceptual drawing of an active yaw control (AYC) differential.

Sawase: No! I came up with it in just three days (laughter).

Motoyama: The initial design was an independent four-wheel drive system that used clutches. What was horrible about the system was that it would not allow you to turn normally. It also allowed the driver to drift the vehicle and experience an exceptional thrill. When I asked my boss to try the vehicle with the system, he said, “It is really difficult to drive but you have something sufficiently worthwhile to develop a way of controlling it”. The conclusion was that we should work on not traction distribution but torque transfer.

Sawase: Yes, I remember that. During the first discussions with Mr. Motoyama, the theme presented was: “development of a lateral traction distribution system”. Then, I initially considered some distribution mechanisms. As the discussion advanced, however, I realized that what needed to be controlled was not the lateral traction distribution ratio but the right-left traction difference that produced the yawing moment. I soon came up with the idea of using the slipping clutch theory, which means that a slipping clutch transmits torque only in one direction. I also thought that an actual system would need a differential gear to allow the vehicle to run normally when the control was inactive. I

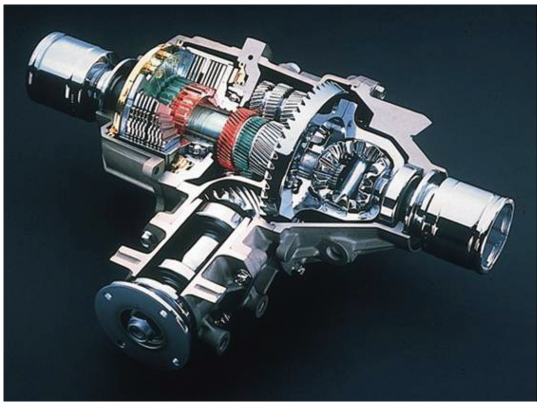

Fig. 2 AYC differential gear (1996 LANCER EVOLUTION IV)

thought of the Automatic Yaw Control (AYC) differential while taking a bath, but the real challenge then began. The first prototype system took the testing staff one full day to assemble and mount on the test vehicle. But, the system broke only five seconds after the test started. At the end of the third of similar breakage, our manager was quite naturally not happy.

Putting these hardships behind us, the AYC system made its debut on the 1996 GALANT/LEGNUM and LANCER EVOLUTION IV. The latest system employed on the EVOLUTION X comes with yaw rate feedback control, the concept that Mr. Motoyama conceived of 10 years ago.

Sawase: Like any first-of-a-kind product, the AYC system initially received a number of negative evaluations. The reason, as you may suppose, was the unpleasant feel the system gave the driver. But, if you completely remove the odd feel, you would not be able to enjoy the benefits of the system, and vice versa. We tirelessly tried to refine the system until it was eventually granted “citizenship”. The LANCER EVOLUTION was the best platform on which to demonstrate the benefits of the system. However, even here, the system received negative comments initially.

Funo: Negative comments?

Sawase: Yes, that the system was “unusual”. In particular, critics said that the system caused the vehicle to turn when the accelerator was pressed and to move outwards when the accelerator was released. The feedforward, tack-in restraining control that prevented the rear inner wheel from tracking too tight a curve in corners was responsible for this, which was excessively effective. This gave the driver an odd feel.

Nishida: It is difficult to stop here, but time is limited today. Someday, perhaps we shall schedule a running discussion of this kind in the Technical Review. By the way, is “torque vectoring” a common expression for the effect being discussed here?

Sawase: Yes, it is the English counterpart of “lateral torque shift”, a direct translation from the Japanese term that we use to indicate the same effect. We can use it as a definite English expression for the effect. Ricardo of England first used it. This expression provided the opportunity for MMC’s AYC system to be identified as an embodiment of the concept in question in Europe. In Japan, the concept is called “Direct Yaw Moment Control” or “DYC”.

Nishida: MMC has now introduced the concept in the All Wheel Control (AWC) and Super All Wheel Control (S-AWC).

Sawase: AWC is a set of 4WD-based technologies to optimally control and use the performance available from the four tires fully. Its most advanced form is the S-AWC system. The system mounted on the LANCER EVOLUTION series is the result of steady enhancement over the years, and its high degree of perfection and speed performance having been verified in a number of races. Application of the technology should not be limited to the LANCER EVOLUTION.

4. S-AWC on the LANCER EVOLUTION X

Nishida: What was the initial market reaction to the S-AWC at the launch of the LANCER EVOLUTION X?

Funo: I attended press events; the S-AWC was given a very high mark. The system enables truly stable driving without the need for the driver to use any special form of control.

Nishida: Were there any “unpleasant feel” comments?

Funo: There were almost no comments of this kind. Compared with the previous model (the LANCER EVOLUTION IX), the new system operates in many more scenarios and with greater control. Nonetheless, the system enables the vehicle to respond faithfully to the driver’s control. The previous system sometimes required the driver to use special maneuvers so that it could fully demonstrate its performance. Such driver considerations are not necessary with the new system. It indeed gives a natural feel. To make this possible, the workload is increased on the part of the vehicle’s system.

Sawase: The driver can control the LANCER EVOLUTION X even in situations where he or she would not be able to handle an ordinary vehicle, during high lateral acceleration cornering for example, without the need for special maneuvers.

Motoyama: I often heard comments like, “It feels as if my driving skills have improved”. Racing drivers made comments like, “It makes driving easier”.

Sawase: It generally has a reputation for being just amazing. The vehicle behaves quite stably. Our development goal for the system was stable running and the market appreciates that goal.

Nishida: How did you determine the target quality of each control factor while building up the overall performance of the system?

Sawase: When we started handling so-called vehicle dynamics control systems, we placed more importance on numerical values than on other factors, but what we now respect more than numerical values is the solid performance of the system during driving tests. We adjust the control factors according to comments and suggestions from test drivers. In development now, we recognize that a goal cannot be determined on numerical values alone, so we do not consider only the data. Indeed, there are good and bad images of a vehicle’s dynamic characteristics, but the image can be expressed in words rather than in numerical values.

Funo: During the development of the S-AWC, we evaluated performance by using a sensory method and the results were expressed in a point rating system. However, the rating alone could not represent the full picture, so we tried to convey our views on the sensation, flavor and feel of the vehicle in close communication with the system developers, using descriptive comments.

Motoyama: I can tell you that data were used only for the presentation at the completion meeting of the system development, ... data that we collected a long time ago (laughter).

Nishida: Were there any negative comments by the participants?

Funo: There were a few. If the system is not in sync with the driver, he or she may initially feel that the system restricts the driver’s control of the vehicle. Some drivers fear that, after trying a vehicle with S-AWC, their driving skill could suffer when they return to their own cars.

Sawase: Even if you are not a highly skilled driver, the system lets you drive with fewer mistakes and, should you make a mistake, the system helps you to quickly recover from it. Paradoxically, this causes concern, but the EVOLUTION X still makes driving fun and helps the driver hone their skills in “toughness and safety” before “upgrading” to cars without S-AWC.

Funo: The excellent performance of the S-AWC can be fully demonstrated provided the vehicle itself has good characteristics. No matter how sophisticated the system, it cannot demonstrate its full capability and the driver cannot enjoy it unless the vehicle itself has solid characteristics. For example, the system cannot perform properly unless the vehicle can reflect the lateral acceleration it receives exactly. The basic performance of the vehicle is very important.

The tires are also key for a successful demonstration of the system’s performance. The tires selected for the LANCER EVOLUTION X were low rolling resistance tires, which now offer good grip due to recent technical developments. As a person who works with system evaluation, I certainly feel that tire performance is generally enhancing. In the LANCER EVOLUTION X, you will find that its tires wear in an even pattern. This shows that the S-AWC acts positively on the tires. The front tires carry a lower load.

We also sought optimum control of road contact loads of the four wheels in developing the AWC system. To obtain better traction and braking control efficiency from tires, you must keep proper control of the tires’ road contact loads. Our success in this area depends significantly on optimizing the vehicle dimensions (a wider track width and lower center of gravity) to prevent excessive variation in the tires’ vertical loads, which would result from load transfer. It is also important to control vertical loads for traction control. Lower vertical loads result in less transmission of traction, which makes it more difficult to control the vehicle’s attitude. Maintaining proper vertical loads for all four wheels provides the basis for effective vehicle attitude control. This has great merit.

Nishida: We also have our own philosophy on body design.

Kondo: The LANCER EVOLUTION X uses aluminum materials for the roof, hood, fenders and bumper beam. By using aluminum in these areas that are far from the center of gravity, we lowered the center of gravity and reduced the moment of inertia. The aluminum hood has another purpose: pedestrian protection. Because a light hood can absorb less energy, it provides less protection for the driver’s head. We specifically designed the shapes of the inner structural components to overcome this problem. Furthermore, structural members are spot-welded at more locations to increase stiffness.

Nishida: I heard that the aluminum roof presented various challenges.

Kondo: Yes, there were a number of obstacles to clear, although I only became involved in the project just before the start of volume production of the LANCER EVOLUTION X. As mentioned before, aluminum roofs lower the center of gravity, but had never been used for mass-produced vehicles in Japan. One of the biggest challenges was the technology needed to join aluminum and steel materials. Generally, spot welding is used for steel-to-steel joints, but this method is not suitable for joining different metals. After trying various alternatives, we chose self-piercing rivets and succeeded in the trial production. We found that in addition to lowering the center of gravity, the aluminum roof substantially reduces rolling moment of inertia, thus enhancing the LANCER EVOLUTION X’s dynamic performance, so we decided to use it.

To cope with electric corrosion, which was another issue, we used an adhesive between the aluminum and steel parts to prevent direct contact, in addition to sealant to prevent water ingress. We also had to address heat distortion. During the body coating process, the roof is heated to as high as 180 ˚C, but at this temperature the body panels tend to distort because aluminum and steel have different coefficients of thermal expansion. So, after extensive study, including CAE analysis, we decided to provide beads on the sides of the roof panel to prevent thermal distortion.

This method has since been applied to the aluminum roof of the OUTLANDER. I have heard that customers like the agility derived from the low center of gravity of these models.

5. Body, chassis, evaluation and analysis

Nishida: Indeed, weight reduction, a low center of gravity and a low moment of inertia are all essential for enhanced dynamic performance of a vehicle. However, simply using aluminum materials causes problems with the rigidity of the body, which has a predominant influence on the vehicle’s dynamic performance. We had to work hard to ensure full rigidity of the body in developing the LANCER EVOLUTION X.

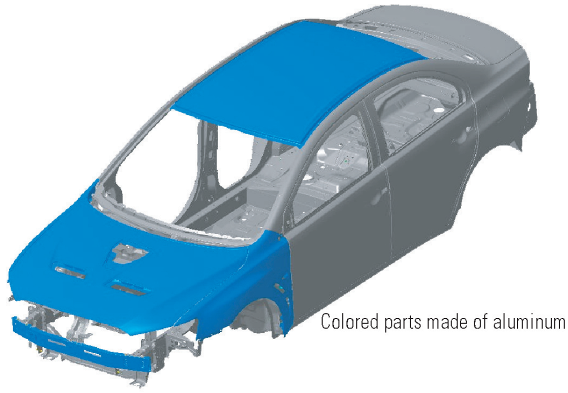

Fig. 3 Body incorporating aluminum (LANCER EVOLUTION X)

We have focused our research on aluminum space-frame body structure technology to reduce vehicle weight. This technology enhances the vehicle’s handling and stability, not only because of its weight reducing effect, but also because it increases the rigidity, especially at joints.

Kondo: That’s right. As generally stated, the Young’s modulus and specific gravity of aluminum are both one third those of steel, which means that its specific rigidity (ratio of stiffness to weight) is also one third that of steel. If aluminum material were simply applied to the body framework for reduced weight, the body would be less rigid. An aluminum space frame structure uses extruded aluminum materials for the main structural members, taking advantage of the material’s characteristics to overcome such issues that are characteristic to steel monocoque body structures, such as a loss of rigidity at joints and spot welds. In addition to a low moment of inertia due to reduced weight, the aluminum space frame body provides the type of ride that is not possible with a steel monocoque structure.

Nishida: That is the synergistic effect of reduced weight and high rigidity. When we think about the positive effect of a space-frame structure on stiffness, we can understand how important joining techniques are to a monocoque body.

Kondo: Increasing the number of spot welds is a widely known method of increasing rigidity. At MMC, this method was first employed for the LANCER EVOLUTION IV, followed by the FTO, PAJERO, COLT and other ranges. Today, continuous joining methods such as laser welding are drawing increasing attention as substitutes for spot welding. Furthermore, an increasing number of automaker’s are positive about using adhesives in combination with welding.

Funo: A body structure built by using a continuous joining method evidently provides enhanced dynamic performance. One of the clearest pieces of evidence is that a vehicle with such a body structure had a lap time of approximately one second less than predicted on the handling circuit in our proving ground.

Nishida: Unlike tires and suspensions, it is difficult to logically express the impact of body characteristics

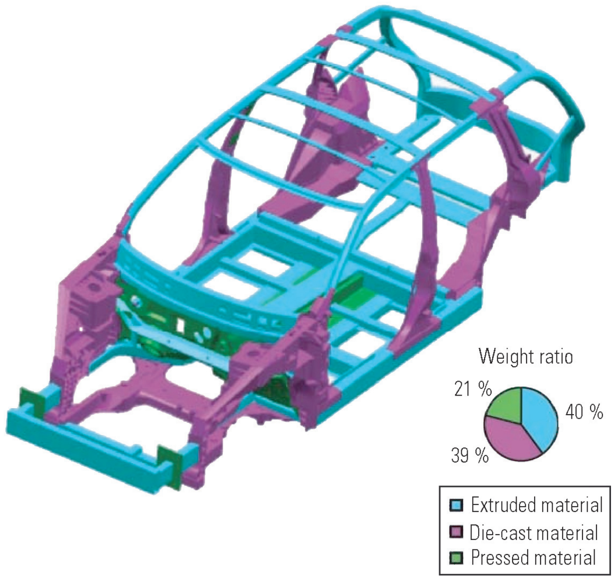

Fig. 4 Aluminum space frame body

on a vehicle's dynamic performance by using mathematical formulae. In actual testing scenarios, staff traditionally use their senses to identify the vehicle's dynamic performance.

It is simple to say "the rigidity of suspension mounts", but it is not simple to define what the phrase means. To begin with, where is the reference point in the coordinates we should use?

Sunouchi: As a member of chassis engineering, I used to focus on increasing the rigidity of suspension members and mounts. I realized, however, that increasing the rigidity of the body framework is crucial. There are areas you cannot enhance no matter how much you intend to increase the suspension stiffness.

Kondo: Flexural stiffness and torsional stiffness are typical values that represent the body's rigidity, but they do not represent everything regarding rigidity. Rigidity is really difficult to express.

Sugimoto: Rigidity of the vehicle's body is difficult to measure. To measure rigidity, the vehicle's body must be fixed in place, but the measurement results obtained from an improperly fixed body may not be what we need. These may represent other things, and you will not understand exactly what you are measuring. We require a method of presenting the force of inertia.

Kondo: It is important to visually confirm the deformation on an actual vehicle body.

In addition to deformation measurement on a body in white (BIW), we used to reproduce the BIW faithfully by using plastic models of individual body parts to see how they deformed. Now, we generally do the same thing on computer screens using CAE technology visually, but the BIW tests were useful to me because I could confirm how those plastic models deformed by physically touching them. It was easy to cause poor structural components to deform by applying a force to them (laughter).

What I have realized about body rigidity is that it cannot be expressed by bending rigidity, torsional rigidity or local rigidity values alone. Unlike collision characteristics or noise, vibration and harshness (NVH) characteristics, the field of handling and stability includes large areas where human sensation plays a part, in other words, intuition. I think it is wrong to examine body rigidity purely by mathematical calculation.

Sugimoto: A well-trained driver testing handling and stability can accurately point out areas of the body that lack rigidity. Currently we are using the software applications that are specially designed for vehicle dynamics analysis but they cannot handle the elastic deformation of the vehicle body.

On the other hand, theoretical interpretations of the effects of suspension geometry and alignment characteristics on the vehicle's handling and stability were established many years ago. Multilink suspension systems, which have been widely employed since the 1980s, are intended to enhance a vehicle's dynamic performance by utilizing their high degree of freedom in designs that incorporate appropriate alignment and compliance characteristics. Large-scale kinematic analysis software was introduced at almost the same time. In software analysis, however, the body was handled as a rigid body. It was not until the 1990s that CAE was applied to deformation of an operating vehicle's body from the viewpoints of the vehicle's handling and stability and riding comfort.

Sunouchi: As a chassis designing engineer, I felt that the body, the foundation of the vehicle, was being left behind (laughter). Geometry control development based on virtual steering axis philosophy and best linkage arrangement of the multilink suspension is worthless without a solid foundation, or body.

Kondo: Today, it is possible to analyze the elastic deformation of an operating vehicle's body by using a combination of multi body analysis and finite element analysis. We need a theoretical analysis of the elastic deformation to find what influence it has on the drivers' senses, as well as on the vehicle's behavior.

Sugimoto: Human senses are extremely delicate, so even today, a driver's assessment during handling and stability testing is often not reflected in the data. Even a difference in data value that is not sufficient to be represented by the width of a line on a graph can represent a great difference for the human senses. However, that amount of difference in human feeling is extremely difficult to use to prompt design changes from designers. In my experience, a designer who tried the vehicle and experienced a distinct difference in feeling criticized us saying, "Why do your data not reflect such a large difference?" Numerical representation of sensory assessment is a big challenge.

6. For the "utmost driving pleasure"

Nishida: Vehicle dynamic control technology can penetrate deeper into areas beyond the ability of the driver, but the ultimate controller is the driver. In this sense, communication between the driver and the vehicle is imperative. Control technology, however, can only work when it is provided with numerical data.

Funo: Vehicle dynamic control technology expands each driver's vehicle control ability and assists with better control. However, it can only do this well when its control logic is tuned to match the vehicle's characteristics as well as the drivers' control habits and expectations. Although the control logic may sometimes be tailored to accentuate an attractive feature of the vehicle, it must at least allow vehicle motion alignment to be fully ensured. Proper feedback of control system operation to the driver should not be perceived as unpleasant, but should rather be perceived as a good thing that provides communication between the driver and the system. However, excessive feedback can generate an unpleasant feel. Feedback must be kept just below the level at which the driver starts perceiving it to be unpleasant.

Equally important is that feedback from the dynamic control system is well balanced with such things as engine response to accelerator operation, even in terms of the quality of sound, as a vehicle is a product of overall balance.

Motoyama: Vehicle systems used to be independently controlled, but are now increasingly integrally controlled. Our goal should be the innovation of individual systems and their integration, to offer enhanced controllability and stability while pushing the limits and also striving towards performance that is harmonized with the drivers' sensation. Control technology should keep a low profile. Even so, it should still be reliable and highly efficient.

An ideal control technology is one that does not give an unpleasant feel because it works as if it were directly linked to the human brain, as if it were intuitively reflecting the driver's intention. I think it will keep growing.

Fig. 5 Driving evaluation

Nishida: After all, the ultimate question should be how control systems can please human senses. Comfort in a vehicle that is responsive to your control will lead to your pleasure in controlling such a vehicle. Some say that younger generations are losing interest in cars while others say that vehicles are only a means of transport. Even if this is true, a vehicle that offers comfort and pleasure should not be a bad means of transport. In this sense, the "utmost driving pleasure" that MMC seeks, is a common goal to be shared by all vehicles, including cars, SUVs, trucks.

Vehicle dynamic control is evolving from a form of independently controlling individual functions to a form of integrally controlling all these functions, which will open up new possibilities. Nevertheless, those areas that are based on sensory assessment, not on numerical data, cannot be easily accommodated in control technology. Anyway, we all understand that no control technology can demonstrate its full capability unless the vehicle's base, namely the specifications, body, suspension and the like, are sound. This is the basis of manufacturing good vehicles.

That's it for today. Thank you everyone.