PASSENGER CARS

Overall Trends

1 Introduction

Despite the slowdown of the Chinese economy and stagnation in emerging markets resulting from low crude oil prices, the automotive industry showed signs of strong consumption in 2015 as employment became stable and income levels recovered in the U.S. and Japan. The Japanese economy, in particular, continued to recover gradually as the yen remained weak.

In the automobile market, sales in major countries rose significantly to 109.2% of the previous year. In developed nations, including the gradually stabilizing European economies, sales exceeded the results of the previous year. At the same time, emerging markets polarized into regions of ongoing expansion such as China or India and regions that experienced a drastic drop in the market, such as Brazil.

2 State of Vehicle Production, Sales, and Exports

2. 1. State of production in leading manufacturing countries

Global production of passenger cars was 68.56 million vehicles, representing 101.2% of the figures from the previous year (Table 1). Although production rose in emerging markets such as China and India as well as in the developed EU nations, it decreased in Japan and the U.S., which have high exports to emerging markets. There was also a remarkable drop in Brazil, where the economy is stagnant.

The top 3 for passenger car production by manufacturer remained unchanged from the previous year, with the Hyundai Group in first place, followed by Toyota, the Volkswagen Group, but among the rest of the top 10, Honda fell from 6th to 10th place, while Ford rose from 14th to 9th (Table 2).

2. 2. State of Japanese vehicle production, exports, and sales

2. 2. 1. Production

The recent trend of decreased production continued as passenger car production in Japan was lower than last year at 7.83 million vehicles, representing 94.6% of the figures for the previous year (Table 3).

While production of ordinary passenger cars rose to 101.9% of the previous year as the weak yen led to more exports, production of compact vehicles and mini-vehicles was lower than in the previous year, with the latter, which are mainly in demand in Japan, dropping significantly to 81.9% of the previous year's level.

2. 2. 2. Exports

The number of passenger cars exported in 2015 rose to 3.97 million vehicles, representing 103.5% of the figures for the previous year. Against the backdrop of the weak yen, exports to Central America, with which an FTA has been concluded, expanded considerably to 121.5% of the previous year, and exports to the Middle East, North

Table 1 Passenger car production in leading manufacturing countries.

		2015	2014	2015 /2014 (%)
Japan		7 830 722	8 277 070	94.6
U.S.		4 163 679	4 253 098	97.9
Canada		888 565	913 533	97.3
	Germany	5 707 938	5 604 026	101.9
	UK	1 587 677	1 528 148	103.9
	France	1 553 800	* 1 499 464	103.6
	Italy	663 139	401 317	165.2
	Spain	2 218 980	1 898 342	116.9
EU		16 368 971	* 15 409 337	106.2
South Korea		4 135 108	4 124 116	100.3
China		21 079 427	* 19 928 505	105.8
India		3 378 063	* 3 162 372	106.8
Brazil		2 018 954	2 502 293	80.7
World total		68 561 896	67 782 035	101.2

* Revised

Note 1) The values announced by the International Organization of Motor Vehicle Manufacturers (OICA) are preliminary figures. There are 27 countries in the EU.

Note 2) The number of vehicles for the U.S. and Canada excludes SUVs and other models that are considered as trucks in those countries.

Table 2 Passenger car production according to manufacturer and country.

Ranking in 2015	Ranking in 2014	Manufacturers	Country	2015	2014	2015 /2014 (%)
1	1	Hyundai group	South Korea	3 183 455	3 208 685	99.2
2	2	Toyota	Japan	2 827 349	2 915 185	97.0
3	3	VW group	Germany	2 327 541	2 252 470	103.3
4	4	BMW	Germany	1 153 283	1 117 778	103.2
5	5	Daimler	Germany	991 313	1 019 028	97.3
6	7	Mazda	Japan	955 961	918 502	104.1
7	9	PSA	France	843 349	843 917	99.9
8	11	Nissan	Japan	755 742	764 230	98.9
9	14	Ford Germany	Germany	743 401	646 435	115.0
10	6	Honda	Japan	730 493	922 533	79.2
11	8	GM	U.S.	725 535	861 483	84.2
12	10	Suzuki	Japan	712 070	825 890	86.2
13	12	Fuji Heavy Industries	Japan	709 749	695 790	102.0
14	13	Honda America	U.S.	678 828	684 196	99.2
15	15	Mitsubishi	Japan	635 441	637 897	99.6
16	17	Toyota	U.S.	629 088	615 019	102.3
17	16	GM Daewoo	South Korea	600 961	623 034	96.5
18	20	Ford	U.S.	550 008	485 349	113.3
19	18	Daihatsu	Japan	530 784	597 043	88.9
20	19	Nissan	UK	476 589	500 238	95.3
21	21	Nissan	U.S.	421 110	461 777	91.2
22	22	Renault	France	405 518	340 667	119.0
23	23	GM Canada	Canada	203 183	247 298	82.2

Source: Automobile manufacturers association in each country and automaker press releases

Table 3 Passenger car production in Japan.

	2015	2014	2015 /2014 (%)
Ordinary cars	4 744 471	4 657 765	101.9
Compact cars	1 555 548	1 750 895	88.8
4-wheeled mini-vehicles	1 530 703	1 868 410	81.9
Total	7 830 722	8 277 070	94.6

Source: Japan Automobile Manufacturers Association

Table 4 Number of passenger cars exported from Japan according to destination.

	2015	2014	2015 /2014 (%)
North America	1 719 428	1 634 915	105.2
Europe	717 980	724 198	99.1
Oceania	344 344	330 765	104.1
Asia	382 586	400 066	95.6
Middle-East	504 159	448 493	112.4
Central America	132 446	109 030	121.5
South America	104 377	123 855	84.3
Africa	61 898	61 342	100.9
Others	2 785	2 931	95.0
Total	3 970 003	3 835 595	103.5

* Revised

Source: Japan Automobile Manufacturers Association

America, Oceania, and Africa were also higher than in the previous year (Table 4).

2. 2. 3. Sales

At 4.21 million vehicles, sales of passenger cars in 2015 dropped to 89.7% of the figures from the previous year. For ordinary and compact cars, the drop compared to the previous years is the result of the last minute demand before the consumption tax increase in 2014 and automaker efforts to prop up sales after that increase. At the same time, sales of mini-vehicles reached record

Table 5 Passenger car sales in Japan.

	2015	2014	2015 /2014 (%)
Ordinary cars	1 354 541	1 437 589	94.2
Compact cars	1 349 944	1 422 883	94.9
4-wheeled mini-vehicles	1 511 404	1 839 119	82.2
Total	4 215 889	4 699 591	89.7

Source: Japan Automobile Manufacturers Association

Note 1) The classification criteria of the sales statistics are based on the license plate number.

Table 6 Used vehicle sales in Japan.

	Ordinary cars	Compact cars	4-wheeled mini-vehicles	Total	Proportion of previous year (%)
1998	1 493 744	3 309 426	1 111 282	5 914 452	97.9%
1999	1 551 703	3 127 783	1 273 383	5 952 869	100.6%
2000	1 742 786	3 050 087	1 448 546	6 241 419	104.8%
2001	1 830 588	2 913 775	1 552 297	6 296 660	100.9%
2002	1 861 694	2 744 604	1 714 827	6 321 125	100.4%
2003	1 910 017	2 640 456	1 809 840	6 360 313	100.6%
2004	1 984 562	2 524 764	1 777 866	6 287 192	98.9%
2005	2 002 563	2 460 410	1 890 154	6 353 127	101.0%
2006	1 959 739	2 304 226	2 033 569	6 297 534	99.1%
2007	1 810 596	2 105 122	2 022 866	5 938 584	94.3%
2008	1 728 090	1 944 766	1 995 333	5 668 189	95.4%
2009	1 619 370	1 855 071	1 864 874	5 339 315	94.2%
2010	1 592 110	1 816 696	1 873 466	5 282 272	98.9%
2011	1 542 614	1 733 519	1 906 523	5 182 656	98.1%
2012	1 688 606	1 826 335	2 133 725	5 648 666	109.0%
2013	1 666 732	1 740 725	2 255 560	5 663 017	100.3%
2014	1 630 421	1 653 214	2 367 235	5 650 870	99.8%
2015	1 668 429	1 602 719	2 354 077	5 625 225	99.5%

Source: Japan Automobile Dealers Association

Source: Japan Light Motor Vehicle and Motorcycle Association

Table 7 Imported vehicle sales in Japan.

Ranking in 2015	Ranking in 2014	Manufacturers	2015	2014	2015 /2014 (%)
1	2	Mercedes-Benz	65 159	60 834	107.1
2	1	VW	54 765	67 438	81.2
3	3	BMW	46 229	45 645	101.3
4	4	Audi	29 414	31 413	93.6
5	6	BMW MINI	21 083	17 596	119.8
6	5	Nissan (vehicles produced outside Japan)	20 481	23 200	88.3
7	7	Volvo	13 510	13 277	101.8
8	9	Jeep	7 129	6 691	106.5
9	12	Porsche	6 690	5 385	124.2
10	8	Fiat	6 032	7 289	82.8
11	10	Peugeot	5 906	5 710	103.4
12	13	Renault	5 082	4 662	109.0
13	14	Ford	4 856	4 598	105.6
14	11	Mitsubishi (vehicles produced outside Japan)	4 102	5 598	73.3
15	15	Land Rover	2 979	3 126	95.3
16	16	Alfa Romeo	2 321	2 661	87.2
17	17	Citroen	1 978	2 321	85.2
18	18	Toyota (vehicles produced outside Japan)	1 036	1 674	61.9
19	20	smart	1 012	1 114	90.8
20	19	Chrysler	464	1 286	36.1
0	—	Others	12 853	8 159	157.5
			300 228	311 518	96.4

* Revised

Source: Japan Automobile Manufacturers Association

Table 8 Passenger car sales in leading manufacturing countries and share of Japanese vehicles.

	2015	Japanese vehicles (within the total)	Share of Japanese vehicles (%)	2014	2015 /2014 (%)
Japan	4 215 889	3 931 418	93.3%	4 699 591	89.7
U.S.	7 525 023	3 291 453	43.7%	* 7 689 110	97.9
Canada	711 785	304 079	42.7%	* 755 544	94.2
Brazil	2 122 956	380 344	17.9%	* 2 794 687	76.0
China	21 146 320	3 534 032	16.7%	19 700 569	107.3
India	2 772 745	1 674 641	60.4%	* 2 574 428	107.9
UK	2 633 503	426 616	16.2%	2 476 435	106.3
Germany	3 206 042	289 876	9.0%	3 036 773	105.6
France	1 917 226	190 479	9.9%	1 795 885	106.8
Italy	1 575 524	165 055	10.5%	* 1 360 578	115.8
EU + EFTA total	14 188 934	1 858 320	13.1%	* 12 996 324	109.2

Source: Automobile manufacturers association in each country

Note 1) Japanese vehicles refer to all Japanese brand vehicles and include those produced outside Japan.

Note 2) The number of vehicles for the U.S. and Canada excludes SUVs and other models that are considered as trucks in those countries (Source: Ward's).

Note 3) Calculated from the 26 countries in the EU and 3 countries in the European Free Trade Association (EFTA: Iceland, Norway, and Switzerland) (source: European Automobile Manufacturers' Association (ACEA)).

* Revised

highs for two consecutive years in 2013 and 2014, but plunged by double digits to 82.2% of the previous year in 2015 (Table 5).

2. 2. 4. Used vehicle sales

The number of used vehicles sold in 2015 remained almost the same at 5.62 million vehicles, 99.5% of the level in the previous year. With the gradual recovery of the economy, sales of ordinary vehicles, which had been declining in the last few years, started to rise again. Sales are also continuing to grow for mini-vehicles, which tend toward longer ownership (Table 6).

2. 2. 5. Imported vehicle sales

Sales of imported vehicles in Japan in 2015 were 3 million vehicles, approximately the same level (96.4%) as in the previous year. By manufactures, Mercedes-Benz and BMW premium brands benefitted from the recovering economy to enjoy higher sales than in the previous year. Volkswagen sales, which were first in 2014, dropped by a little over 10,000 vehicles to slip down to second place (Table 7).

3 Vehicle sales in markets outside Japan

Sales of passenger cars in all major developed countries other than Japan were at the same or a slightly higher level than in the previous year. In Japan, the impact of the front-loading of the demand that preceded the 2014 tax increase has been significant.

At the same time, emerging markets polarized between China and India, where sales exceeded those of the previous year, and Brazil, where they fell below that level as they were strongly affected by the economic downturn following the slowdown in China, low crude oil prices, and high foreign currencies.

Japanese models, led by Toyota, Honda and Nissan, had a market share exceeding 40% in North America, and a 60% share in India through Suzuki, Honda, Toyota and other automakers.

Design Trends

1 Introduction

A look back at 2015 shows that in addition to the eco and crossover categories becoming well established, sports cars were a common topic in all segments across the entire range from light and small to premium vehicles. This reflects the considerable influence of the strong sales of environmentally friendly vehicles and mini-vehicles and the growth in the premium segment spurred by the robust North American economies.

After looking at each of the following topics in detail, it will be concluded with observations on the sweeping tide of the times symbolized by automated driving.

2 Pursuit of Added Value for Environmentally Friendly Vehicles

In dedicated hybrid vehicles and other vehicle that have touted environmental and fuel economy performance, efforts have been turning to enhancing product appeal by focusing on added values in addition to improvements in performance. Such efforts are being undertaken because the progress in installing hybrid systems on existing models and their popularization around the world means that promoting environmental or economic benefits alone is no longer sufficient to entice customers. This is especially noticeable for cars at or above the midpoint of the price range.

Fig. 1 Toyota Prius

The Toyota Prius (Fig. 1), which was completely redesigned in December 2015, emphasizes the excellent driving performance achieved by adopting the Toyota New Global Architecture (TNGA) platform in addition to improved environmental performance. The exterior design therefore conveys of a low center of gravity, sporty shape that evokes driving dynamics and, paired with the triangle silhouette that symbolizes aerodynamics, boldly expresses environmental friendliness and emotional styling to present a unique appeal. Moreover, features such as the unique and attractive instrument panel focused on intuitive operation and the world's first vivid body color with heat shielding capabilities appeal the fusion of functionality and emotional styling.

The extended range Chevrolet Volt (Fig. 2) capitalizes on its large capacity battery to offer comforts such as rear seat heaters, advances in operation and communication systems based on its unique large display screen

Fig. 2 Chevrolet Volt (exterior appearance)

Fig. 3 Chevrolet Volt (interior appearance)

Fig. 4 Bentley Bentayga

Fig. 5 Jaguar F-Pace

Fig. 6 Lexus RX

Fig. 7 BMW X1

(Fig. 3) and achieves a sporty style that reflects its improved acceleration. These and other advances in basic performance coupled with added value features convey the intent to build a new added value format characteristic of electric vehicles.

If the robust economy and low crude oil prices observed in North American markets this year persist, hybrid, electric and other environmentally friendly vehicles will have to offer their own distinctive added value to counter the attention directed at the premium segment and large pickup trucks.

Fig. 8 Toyota C-HR

Fig. 9 Nissan Gripz

Fig. 10 Fiat 500X

Fig. 11 Jeep Renegade

3 Expanding Market Penetration and Differentiation on Various Levels for Crossovers

The unbroken momentum exhibited by crossovers in the last few years remains strong, and they have drawn attention with their expansion into the upper luxurious segment seen at the International Motor Show Germany in Frankfurt. The launch of crossovers such as the Bentley Bentayga (Fig. 4) or the Jaguar F-Pace (Fig. 5) was announced by luxury brands whose lineup did not include such vehicles. Prodded by the successes of Porsche, BMW and other early crossover adopters, these luxury brands are endeavoring to capitalize on their brand image to differentiate their products and make them allur-

Fig. 12 Mazda Roadster

ing. The Jaguar F-Pace features specs that target the Porsche Macan as a potential competitor, and a characteristic Jaguar design whose sporty and elegant shape expresses its individuality in the increasingly and fiercely competitive high-end segment.

As the market becomes saturated with a flood of new entrants, the forerunner of crossovers, the Lexus RX (Fig. 6), has reached its fourth generation, which leverages its pioneering legacy while striving for a distinctive design. Even though its silhouette continues to evoke earlier RX models, characteristics such as providing a next sense of taste by balancing its bold 3 dimensional construction with elaborately placed character lines, as well as its elegant and light cabin graphics, give it an intricate feel despite its large body.

In contrast, the mainstream compact segment more firmly established the category while also presenting efforts at differentiation. The BMW X1 (Fig. 7) switches from the rear-wheel drive of the previous generation to a front-wheel drive platform in an effort to reduce weight and share platforms through its crossover lineup. The raised vehicle height combines with enhancements such as more interior space, greater comfort, and higher storage capacity to achieve a sporty style while strengthening its functional value. Entry models are intended to attract a broad range of users, and this reflects the need for practicality even in premium vehicles.

In contrast, the Toyota C-HR (Fig. 8) and Nissan Gripz (Fig. 9) present examples of taking a different direction in expanding crossover characteristics, choosing to focus on the ease of driving and exhilaration provided by better visibility offered by the higher eyepoint compared to ordinary passenger cars. Based on those characteristics, both vehicles pursue a sporty direction and enhance the "active" impression with tires that seem relatively larger due to the compact body that are even further emphasized by their overall design.

Examples of brand leveraging used for differentiation include the Fiat 500X from Fiat Chrysler Automobiles (Fig. 10), and the Renegade from Jeep (Fig. 11). Each of

Fig. 13 Ford GT

Fig. 14 Ford GT

Fig. 15 Porsche Mission E

Fig. 16 Acura NSX

Fig. 17 Honda S660

these vehicles combines platform-sharing with a design that capitalizes on brand characteristics to achieve efficient development and respond to diversifying market needs.

The original appeal of crossovers lay in their combination of practical merits such as out-of-the-ordinary evocation of leisure, better visibility, and ease of ingress/egress. In an ever diversifying market, clarifying and

Fig. 18 Mercedes-Benz F015 Luxury in Motion

strengthening the selling points are to be expected. This will be done by focusing on specific values and further reinforcing them or by adding new ones to an iconic brand.

4 Enriching Brand Image through Sports Cars

Many striking models were announced in the past year, of which the Mazda Roadster (Fig. 12) is an excellent example.

Rated so highly that it won awards such as the 2016 World Car of the Year and World Car Design of the Year as well as the Car of the Year Japan, this car does not compromise on the joy of handling and is also recognized for its continued presence in the market. The Roadster not only contributed to raising awareness of and improving the Mazda brand image, but also challenged the status of the car from being just a functional tool. The design follows the concept of *jinba ittai* (rider and horse as one) and aims to intensify the sense of vitality of Mazda's unique "soul in motion design". The low center of gravity and accentuated exterior styling embodies modern lightweight sportiness through tense surfaces and line puality as well as a 3 dimensional construction of large volumes.

The vehicle also advocates beautiful proportions that make the driver look good, which is considered a crucial point in this category where driving with an open top is assumed. In this day and age where Internet-based impressions are pervasive, visibly conveying enjoyment via the people driving the vehicle represent a highly effective form of communication. Such goals also constitute major elements of brand image creation.

The Ford GT announced in Detroit (Fig. 13) presents the allure of youth and vigor while also unmistakably reflecting environmental concerns and technological trends. This second generation of the 2005 revival model represents an example of building upon the brand heritage of

Fig. 19 Nissan IDS Concept (Manual Drive)

Fig. 20 Nissan IDS Concept (Piloted Drive)

the original Ford GT40, a race car whose success includes winning the 24 Hours of Le Mans in the past, is well-known and popular in Europe and around the world. In counterpoint to its styling and driving performance closely resembling those of a race car, its turbocharged, small displacement engine and light weight also promote its consideration for the environment. Visible appeals to environmental performance are important and need to be reflected in the design. In the pursuit of improved aerodynamic performance, the rear of the Ford GT cabin has been tapered with thin panels of structural material connecting the roof to the rear fender (Fig. 14). This is a shape made possible by the use of carbon fiber in its basic structure and outer panels, which visually express the aerodynamic, lightweight construction. Design trends reflect the ideas of their time, not only for cars, but also in general. The theme of lightness is in vogue, and the expressions of layering and floating themes seen in the fashion and construction industries are also influencing automobile design.

The Porsche Mission E (Fig. 15) announced at the International Motor Show Germany is gathering attention as a concept study of the transition to PHVs and EVs by brands that have traditionally espoused high class and high performance. In addition to realizing high EV performance, it features a simple, agile and attractive design that seeks to become the symbol of a new Porsche era.

The Acura NSX (Fig. 16) also falls in the super sports car category while demonstrating the unique concept of a three-motor HV with a mid-engine layout as for the

Honda S660 (Fig. 17) takes advantage of the mini-vehicle classification to promote accessible enjoyment of a sports car. Both cars have a condensed shape and silhouette that conveys a low center of gravity in the middle of the vehicle and emphasizes their mid-engine layout. Their dedication to the mid-engine layout evokes the strong connection of Acura and Honda to motor sports, and contributes to brand differentiation.

5 Issues in Automated Driving and Influence on Design

This section will conclude with a look at automated driving. The number of concept studies unveiled at motor shows rose, as did, in conjunction, the number of exhibits at events such as the Consumer Electronics Show (CES, an electronics trade show held in North America), making 2015 a year that strongly hinted at commercialization on the horizon.

Among representative show models, the Mercedes-Benz F015 (Fig. 18) treats the cabin as a moving lounge, and combines a modern and flexible interior design with advanced technologies to offer a vision of a new mobility experience and utility value. The Nissan IDS concept (Figs. 19 and 20) proposes a steering wheel that is replaced by a wide screen enabling activities such as video conferencing when not driving. These concepts illustrate how, in addition to safety and efficient driving, which constitute the basic benefits of automated driving, the services provided during non-driving periods is also important element of commercialization.

The exploration of various concepts is expected to continue within and without the automotive industry. In contrast to projects such as the Google self-driving car where humans are not involved in driving at all, automakers are envisioning situations where control of driving is passed back and forth between the driver and the vehicle. This vision stems from an understanding that automated driving is the culmination of advanced driver assistance systems continuously evolving from their present state.

The pressing issue in that respect, particularly in terms of impact on interior design and styling, is how to achieve a safe and seamless handover of driving control. The typical scenario involves a driver who is less alert, or settled in a comfortable position, when the car hands control over. This will require establishing principles and methods, as well as attendant designs and equipment, to restore mental and physical driving readiness. It is becoming imperative to address this issue through means such as packaging and interfaces in conjunction with realizing the aforementioned services for non-driving periods.

In terms of exterior design, the installation of the sensors and cameras typical of the lidar (light imaging, detection and ranging) systems used for peripheral monitoring and communication is necessary and calls for ingenious approaches to either harmoniously integrate them in the styling or, on the contrary, tackle the challenge of finding new forms of expression. On a different note, cases where the vehicle failed to properly integrate the flow of traffic and became an on-road obstruction have been observed in field tests, and, particularly during the period of transition, systems involving external communication with vehicles or pedestrians in the vicinity that must be taken into account are also among the responsibility of design.

Along with the above mentioned issues it necessary to ascertain the degree of social acceptance of automated driving, including technologies such as connected cars and artificial intelligence, and to use design principles to make expected functions congenial.

6 Summary: the Expanding Scope of Design

The importance of products with a high added value was once again demonstrated in 2015, with particular emphasis placed on emotional values such as a sense of style or fun looks. This can be said to reflect the modern desire to focus on sensitivity without sacrificing affordability or convenience. Design has a major role to play in that context. The higher the flexibility in terms of range and potential combinations of values, as exemplified by categories such as crossovers, the easier it becomes to exercise creativity, opening up the possibility aesthetically stimulating designs. This is undoubtedly one of the factors in their enduring popularity.

Moreover, user experience (UX) design is becoming vital to the commercialization of automated driving. This area of design is not limited to driving operations, but rather encompasses services tying in to all of everyday life, and the emergence of non-driving periods may turn the expansion of convenience and emotional values into a new frontier.

While technological breakthroughs are anticipated to lead to the spread of efficiency-focused transportation services, emotional appeal is also likely to be required of personal transportation. As the mobile society diversifies to encompass those two extremes as well as the area between them, there is a need to apply creativity to further improve "mobility values" rooted in their respective original benefits.

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Body Structures

1 Trends in Body Structures

Fuel economy regulations worldwide are becoming more stringent year after year in an effort to halt global warming. In the United States, required fuel economy values will be gradually raised starting in 2017 and approximately double by 2025. Methods to measure those fuel economy values are also becoming stricter. Europe has proposed setting CO_2 emissions limits of 130 g/km or less in 2015, lowering them to 95 g/km or less in 2021, and reducing them to between 68 and 75 g/km in 2025. Such regulations will continue to spread around the world, and by 2025, a little over 30 countries will have implemented some form of regulations.

In that context, the fourth-generation Toyota Prius launched in Japan has increased the efficiency of various units and enhanced aerodynamic characteristics to achieve a fuel economy value of 40.8 km/L in the JC08 test cycle, a considerable improvement over the 32.6 km/L of the previous generation. In contrast, major German automakers led the way in unveiling a succession of plug-in hybrid vehicles (PHEVs), that reached six models, including the Volkswagen Golf GTE and BMW X5 xDrive40e. Given the European focus on renewable energies, systematic tax benefits applied to PHEVs, which can drive without producing emissions, probably acted as an incentive. For its part, Toyota has announced its intention to eliminate almost all of the gasoline and diesel vehicles that currently represent the majority of its sales and transition is main lines to PHEV, FCV and EV models as part of a policy to reduce CO_2 emissions by 90% compared to 2010 levels[1].

The introduction of electrification technologies and the incorporation of batteries and other newly adopted components, as well as the recent addition of functional parts to support automated driving, are leading the weight of automobiles to increase drastically. Weight reduction will prove more important than ever in improving fuel economy values without worsening the vehicle dynamics expected of vehicles or degrading the crashworthiness that defines body deformation. This section presents an overview of 2015 trends in body structure technologies from the point of view of achieving both body performance and weight reduction.

2 Technological Trends Concerning Required Body Performance

2. 1. Stability and controllability

Stability and controllability go beyond providing the driver with the joy of controlling the vehicle as desired and represent essential capabilities enabling worry-free driving under various environment and road surface conditions. Automakers are therefore pursuing a variety of initiatives in that vein.

The mainstream approach in actual vehicle development involves integrating quantitative parameters for the vehicle body, including the suspension and steering characteristics, based on the results of subjective evaluations as well as the correlation between and measured vehicle behavior data and simulations.

Recently, the spotlight is on the strong and weak points of vehicle behavior relative to driver awareness and operations, and evaluation methods that assess handling from the standpoints of ease of driving and inspiring confidence. Research reports that drivers are sensitive to vehicle yaw acceleration[2] and feel responsiveness through steering effort[3]. Efforts to parameterize vehicle characteristics according to such human feelings are likely to intensify.

2. 2. Noise, vibration, and harshness (NVH) performance

One of the trends observed recently is the improvement of NVH performance in comparatively inexpensive cars. The Mazda CX-3 uses the rear seats as dynamic dampers to improve the damping performance of the vehicle body and attenuate the unpleasant vibrations transmitted to the occupants[4] Inexpensive cars provide little leeway to allocate significant cost or mass to acoustic materials, making it important to understand the vibration mode of the vehicle and creatively engineer the frame and panel shapes to obtain characteristics with no pronounced vibration peak.

The vibration and sound insulation characteristics required of vehicles is anticipated to change when powertrains eventually transition from internal combustion engines to electric motors.

2. 3. Safety performance

Based on investigations of real-world accidents, stricter assessments of passive safety functions aimed at reducing the number of fatalities are anticipated to continue. Higher speeds for existing impact types, or the introduction of new types such as frontal pole impacts, are under consideration. This therefore calls for frame placement and ideas providing even greater energy absorption efficiency.

3 Technological Trends to Mitigate Weight Increase and Satisfy Performance

3. 1. Material ideas

3. 1. 1. Steel sheets

Ultra high tensile strength materials such as 1,180 MPa class cold rolled steel sheets or 1,500 MPa class die quenched material is used for frame members that do not deform in an impact, and designs using thinner sheets are becoming well-established. Although cold rolled material is less expensive than die quenched material, formability is an issue as residual stress during press forming causes deformation. Automakers are using CAE to ensure the necessary accuracy via high shape freezability or the addition of estimates[5]. As a result, 780 MPa class or higher ultra high tensile strength materials generally accounts for 20 to 30% of all materials used.

These ultra high tensile strength materials have little elongation, and using them in the front and rear vehicle body crumple zones causes fracturing during impact deformation, making it difficult to obtain the intended amount of energy absorption. A process that partially applies the quenching operation for die quenched materials is therefore adopted. In the Honda Civic, the rear floor side members are reportedly formed integrally, with ductility only applied to the rear portion that per-

Fig. 1 Ford F150[7]

mits deformation to secure the required performance.

3. 1. 2. Aluminum

Due to cost considerations, the use of aluminum in inexpensive cars is not expanding, but in trucks, the Ford F150 (Fig. 1) uses it for most of its body parts, achieving an impressive weight reduction of 320 kg. The cabin frame uses heat treated 6000 series aluminum subjected to precipitation strengthening to make it stronger and thinner. Applying the heat treatment after forming sets up a process that prevents cracking during forming.

Multi-material structures using different materials in different portions are becoming increasingly prevalent in luxury brands by European manufacturers. The Audi Q7 (Fig. 2), BMW 7 Series (Fig. 3) and Cadillac CT6 have all used that approach to reduce weight by more than 70 kg. For each portion, a material matching the required rigidity and strength levels at a low cost and minimum weight is chosen among steel sheets, aluminum and plastics to realize a light, high-performance vehicle body.

The Q7 and CT6 use steel sheets for the inner frame while applying aluminum to outer panels on the outer body sides and the roof. Those choices are attributed to steel sheets achieving strength and reduced weight equivalent to that of aluminum at a lower cost. The need for weight reduction will only continue to increase, and the adoption of aluminum is expected to expand, especially in SUVs and luxury vehicles.

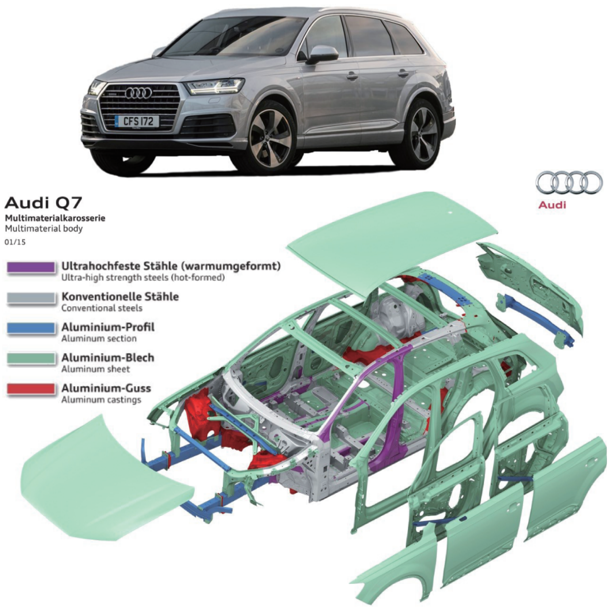

Fig. 2 Audi Q7[8]

Fig. 3 BMW 7 Series[9]

3. 1. 3. CFRPs

Having significantly shortened the conventional CFRP molding cycle, BMW started mass producing the i3 for the first time in 2013. That technology has also been used in the new 7 Series model. Where the i3 featured a cabin consisting entirely of CFRP, the 7 Series sought even greater weight reduction in terms of the ratio to the metal part of the vehicle body by primarily attaching the CFRP to part of the metal cabin frame. This material is expected to become more widely adopted when cost reducing technologies advance further.

3. 1. 4. Joining

In the spot welding of high strength steel, welding strength generally does not rise in proportion to the strength of the steel sheets because heat-affected areas manifest at the circumferential edge portion and decrease strength. Consequently, initiatives such as extending the current application time, or widening the nugget diameter through measures such as raising the accuracy of the body to increase the contact surface area between sheets, are being carried out.

Cases involving the concurrent use of spot welding and laser welding or bonding for the purpose of further improving strength and rigidity have become more common. After using laser screw welding (LSW) for the Lexus NX, Toyota extended its scope and also applied it to the new Prius.

Tremendous advances are being made in technologies to bind different materials such as aluminum or CFRPs to steel sheets, as those technologies are essential to weight reduction. Matching various rivets or screws to the materials in use ensures joining as firm as spot welding in a stable manner.

While increasing the use ratio of materials with high strength or a low specific gravity reduces weight, it also makes repairs more difficult and increases the burden on the end user, which simultaneously creates a greater need for less expensive materials and structural designs.

3. 2. Structure ideas

3. 2. 1. Structural continuity

In 2012, Honda became the first automaker in Japan to adopt an inner frame structure, following up its use in the N Series and the Fit with its adoption in the new Civic models produced outside Japan. It eliminated the need for service holes required for the welding gun to access the frame joints by only adding a welding process for the inner panels, thereby efficiently increasing torsional rigidity (a 25% improvement over the previous generation). This structure, which makes it possible to increase performance without adding mass, could spread to other manufacturers. In a different vein, various structures are being suggested for tailgate openings, which play an important role in ensuring the body rigidity in two-box vehicles.

3. 2. 2. Cross-section optimization

Beyond the obvious possibility of determining the lightest size and shape allowing full use of cross-sectional strength without redundancy, evolving CAE technologies also allows designers to use data mining to optimally balance multiple frames[10]. A technique that sets foamable plastic in the cross-section and applies localized cross-section strength increases was developed for the Mazda Demio launched in 2014, and it is expected to see broader use as a technology that utilizes raw materials to the fullest.

3.2.3. Optimal frame placement

A growing number of vehicles are adopting second member structures designed to absorb frontal impacts as a means of dispersing loads. Combined with analyses of real world accidents, these structures are likely to be applied in assessing accident patterns from all directions to reduce the number of fatalities. The placement of vehicle body frames will have to secure even higher levels of high robustness performance to withstand impacts from various objects and directions. Topology optimization has potential as an effective tool for analysis.

As stated above, many recently launched vehicles have achieved considerable weight reduction while enhancing performance. Further advances in technologies involving material substitution, structure optimization, or joint strengthening are anticipated to accelerate the development of weight reduction technologies.

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