GASOLINE ENGINES

1 Introduction

In 2017, the movement to promote the electrification of powertrains intensified in various countries. In Europe, France and the U.K. announced a policy to ban sales of gasoline and diesel vehicles in 2040. In the U.S., notwithstanding the birth of the Trump administration led to a withdrawal from the Paris Agreement and a revision of the fuel economy regulations, stricter zero emission vehicle (ZEV) regulations were set for 2018 in California and other states, and demand for electric vehicles is rising. Even the emerging country of China has introduced regulations mandating that 10% of production and sales in 2019 consist of new energy vehicles (NEVs). Under these circumstances, one automaker after another announced policies to advance electrification. Nevertheless, there is still high demand for technological breakthroughs in raising engine efficiency and lowering emissions to comply with the latest fuel economy regulations and the Real Driving Emissions (RDE) regulations, and both the introduction of new technologies for engines and the refinement of existing ones are being vigorously pursued.

This article introduces the new technologies used in the typical gasoline engines launched or announced in 2017, and also gives an overview of research and development trends for such engines.

2 Japan

2. 1. Overview

Sales of new vehicles in Japan in 2017 were robust, reaching 5.23 million vehicles, an increase of 5.3% compared to 2016 (total for registered and mini-vehicles), with sales of mini-vehicles alone increasing by 6.8%. The proportion of hybrid electric vehicles (HEVs) for passenger vehicles, including mini-vehicles, rose to over 30% in 2016. Proactive upgrades continue to be applied to improve the fuel efficiency of gasoline engines for both conventional and hybrid electric vehicles. In engines for HEVs, a higher compression ratio and other refinements have achieved a maximum thermal efficiency of 41%. In engines for conventional vehicles higher efficiency naturally aspirated (NA) engines and downsized turbocharged engines are being introduced. Moreover, the introduction of mass production for the variable compression ratio and compression ignition combustion, considered difficult to mass produce until now despite the high degree of fuel consumption decrease effectiveness these engines exhibit.

2. 2. Trends of Each Manufacturer

Table 1 presents a list of the new engine launched or announced by the various Japanese manufacturers in 2017, and an overview of the engines is presented below (including engines by Japanese manufacturers launched or announced outside Japan)

2. 2. 1. Toyota

Building on the key foundation represented by the newly developed high-speed combustion, 2.5-liter 4-cylinder NA engines and 3.5-liter V6 turbocharged engines were introduced, while the 3.5-liter V6 NA engines in the current lineup were upgraded. For the 2.5-liter engines, the A25A-FKS (Fig. 1) was installed in the global mid-size sedan Camry (for North America) conventional vehicle in March, while the A25A-FXS was installed in the HEV Camry (for North America or Japan), with both launched for sale. The basic structure was revised, a long stroke design and higher compression ratio were applied, the intake and exhaust direction was modified, and the valve angle was increased, and technologies such as laser-clad valve seats, high energy ignition coils, and a high-capacity cooled EGR system were adopted to achieve a thermal efficiency of 40% in the conventional vehicle version and 41% in the HEV version, complying with the emissions regulations in various countries and providing a 60 kW/L output performance[(1)(2)]. The 3.5-liter V6 turbocharged V35A-FTS (Fig. 2), installed in the new Lexus LS 500 flagship sedan, was launched in October. It

Table 1 Main new engines in Japan in 2017

Manufacturers	Engine model*1	Cylinder arrangement	Bore × stroke (mm) (S/B ratio (–))	Displacement (cc)	Compression ratio (–)	IN/EXVVT valve train*2 specifications IN/EX	Intake system	Fuel injection system*3	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Characteristics
Toyota	A25 A-FKS	L4	ϕ87.5 × 103.4 (1.18)	2,487	13.0	DOHC 4-valve Roller rocker Electric/hydraulic	NA	S-DI (20 MPa) +PFI	151/6,600	250/5,000	North American Camry (Conv.)	High tumble port, intake laser-clad valve seats, long stroke design, Atkinson cycle (late intake closing) (A25 A-FXS only), electric variable displacement oil pump, water jacket spacer, electric water pump (WP) with path switching valve (variable cooling system), cooled EGR.
	A25 A-FXS	L4	ϕ87.5 × 103.4 (1.18)	2,487	14.0	DOHC 4-valve Roller rocker Electric/hydraulic	NA	S-DI (20 MPa) +PFI	130/5,700	220/3,600 – 5,200	CAMRY (HEV)	
	8 GR-FXS	V6	ϕ94.0 × 83.0 (0.88)	3,456	13.0	DOHC 4-valve Roller rocker Hydraulic/hydraulic	NA	S-DI (20 MPa) +PFI	220/6,600	356/5,100	LC500 h (HEV)	Exhaust manifold integrated in head (3-1 merged headers), intake midpoint lock variable valve timing (VVT), cooled EGR.
	V35 A-FTS	V6	ϕ85.5 × 100.0 (1.17)	3,444	10.4	DOHC 4-valve Roller rocker Electric/hydraulic	TC	S-DI (20 MPa) +PFI	310/6,000	600/1,600–4,800	LS500 (Conv.)	High tumble port, intake laser-clad valve seats, exhaust manifold integrated in head (3-1 merged headers), long stroke design, sodium filled valves, water control valve, twin turbochargers, electric wastegate valve (WGV)
Nissan	KR20 D DET (Not released)	L4	ϕ84.0 × 88.9 (ε14) to 90.1 (ε8) (1.06 to 1.07)	1,970 (ε14) to 1,997 (ε8)	8.0 to 14.0	DOHC 4-valve Direct tappet Electric/hydraulic	TC	S-DI (20 MPa) +PFI	200/5,600	390/1,600 to 4,800	Infiniti QX50 (Conv.)	Variable compression ratio (multilink mechanism) (world first), high tumble port, tumble control valve, exhaust manifold integrated in head (4-1 merged headers), mirror bore coating (without steel liner), Atkinson cycle (late intake closing, VVT), no secondary balancer, two-stage variable oil pump, water control valve (coolant stoppage during warm-up), electric WGV, weight reduction (−18 kg over V6 engine).
Honda	S07 B	L3	ϕ60.0 × 77.6 (1.29)	658	12.0	DOHC 4-valve Roller rocker Hydraulic/ —	NA	PFI	43/7,300	65/4,800	N-Box (Conv.)	High tumble port, exhaust manifold integrated in head (3-1 merged headers), intake VTEC (switching between two cam lobes, mini-vehicle first), mirror finish valves (world first), M10 spark plugs.
					9.8	DOHC 4-valve Roller rocker Hydraulic/ —	TC	PFI	47/6,000	104/2,600	N-Box (Conv.)	High tumble port, exhaust manifold integrated in head (3-1 merged headers), mirror finish valves (world first), electric WGV (mini-vehicle first) M10 spark plugs.
Mazda	PY-RPS	L4	ϕ89.0 × 100.0 (1.12)	2,488	13.0	DOHC 4-valve Roller rocker Electric/hydraulic	NA	S-DI (30 MPa)	140/6,000	251/4,000	CX-5 Atenza (Conv.)	Cylinder deactivation (#1 &4 deactivated, switchable hydraulic lash adjuster (S-HLA)), asymmetric piston rings, edge-cut pistons, centrifugal pendulum absorber, variable displacement oil pump, coolant control valve, low penetration injector, Euro 6 d
	Undisclosed (SKY- ACTIV-X) (Not released)	L4	Undisclosed	2,000	Undisclosed	DOHC 4-valve Roller rocker Electric/electric	High-response air supplier	C-DI	Undisclosed	Undisclosed	Undisclosed (Conv.)	Spark Controlled Compression Ignition (SPCCI, world first), super lean burn, cooled EGR

Table 1 Main new gasoline engines in Japan in 2017 (cont.)

Manufacturers	Engine model*1	Cylinder arrangement	Bore × stroke (mm) (S/B ratio (–))	Displacement (cc)	Compression ratio (–)	VVT valve train*2 specifications IN/EX	Intake system	Fuel injection system*3	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main vehicles equipped with this motor	Characteristics
Subaru	FA24 (Not released)	H4	ϕ94.0 × 86.0 (0.91)	2,387	Undisclosed	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	S-DI	194/5,600	376/2,000 – 4,800	North America Ascent (Conv.)	Undisclosed
Suzuki	K14 C	L4	ϕ73.0 × 81.9 (1.12)	1,371	9.9	DOHC 4-valve Roller rocker Hydraulic/ —	TC	S-DI (20 MPa)	100/5,500	210/2,100– 4,000	Escudo (Conv.)	Exhaust manifold integrated in head (4-1 merged headers), single-scroll turbocharger
									103/5,500	230/2,500 – 3,500	Swift Sport (Conv.)	WGV normal close control
Mitsubishi	4 B40	L4	ϕ75.0 × 84.8 (1.13)	1,498	10.0	DOHC 4-valve Direct tappet Hydraulic/ hydraulic	TC	S-DI (20 MPa) + PFI	110/5,500	240/2,000– 3,500	Eclipse Cross (Conv.)	Exhaust manifold integrated in head (4-1 merged headers), hollow-head sodium filled valves, inclined flow turbine (single-scroll), electric WGV

*1 : Engines announced between January and December 2017 but not yet on sale are indicated as "not released".
*2 : In this article, VVT is used as a unified designation for camshaft position variable mechanisms.
*3: S-DI and C-DI represent, respectively, side and center layout direct injection, and the figure in parentheses indicates the direct injection maximum fuel pressure.

Fig.1 TOYOTA A25A-FKS

Fig. 2 TOYOTA V35A-FTS

features a newly developed in-house compact high efficiency turbocharger, laser-clad valve seats and piston exhaust cooling by multi-point oil jets to achieve a maximum output of 310 kW, a maximum torque of 600 Nm, and a maximum thermal efficiency of 37%[1][3].

Fig. 3 HONDA S07B NA

2. 2. 2. Nissan

No new engines were launched in 2017, but a press release and technical paper concerning the 2.0-liter 4-cylinder turbocharged KR20DDET (VC-Turbo), the world's first mass-produced variable compression ratio engine, which was installed in the new Infiniti QX50 premium SUV model launched in March 2018, were published. In addition to detailing the multilink mechanism, the paper and press release describe the technologies used, which include the exhaust manifold integrated in the cylinder head, mirror bore coating, and a water control valve to stop the flow of coolant during warm-up[1][4].

2. 2. 3. Honda

The 0.66-liter NA (Fig. 3) and turbocharged S07B (Fig. 4,) installed in new models of the N-Box mini-vehicles, were launched in August. The stroke/bore ratio has been expanded to 1.29 from the 1.07 of the previous mod-

Fig. 4 HONDA S07B Turbocharged

Fig. 5 MAZDA SKYACTIV-X

el (S07A), and cooling loss was decreased by reducing the surface-to-volume (S/V) ratio of the combustion chamber. The use of a stronger tumble flow in the combustion chamber and of the world's first mirror finish valves increase knock resistance and improve thermal efficiency. In addition, the NA engine represents the first use of VTEC (switching between two cam lobes) in a mini-vehicle, and the turbocharged engine's use of an electric wastegate valve is similarly a first in a mini-vehicle. Lower fuel consumption is achieved in conjunction with, respectively, better acceleration performance in the NA engine and quicker response in the turbocharged engine.

2. 2. 4. Mazda

The upgraded SKYACTIV-G 2.5-liter 4-cylinder PY-RPS engine, installed in the North American CX-5 crossover, was launched in December. It includes new technologies such as a cylinder deactivation system that relies on a switchable hydraulic lash adjuster (S-HLA), a variable displacement oil pump, and a coolant control valve to improve fuel efficiency in the lighter load range and during warm-up. In the S-HLA, the tip of the lash adjuster is designed to move up and down when pressure releases the internal lock pin, at which time the roller rocker is pushed toward the S-HLA rather than the valve, with the up-down movement stopping the opening and closing of the valve and deactivating the cylinder[5]. In August, announced the introduction of the SKYACTIV-X (Fig. 5) featuring Mazda's proprietary, world-first Spark Controlled Compression Ignition (SPCCI) combustion method. The SPCCI method creates an expanding flame kernel at the spark plug in a compressed lean air-fuel mixture, further compressing the air-fuel mixture which triggers multiple simultaneous self-ignition. This

Fig.6 SUZUKI K14C

2.0-liter 4-cylinder engine features a highly responsive air supplier and a center layout direct injection system, and the ultra-high cylinder pressure enables super lean burn with an air/fuel ratio exceeding 30. Compared to the current SKYACTIV-G 2.0-liter engine, torque has been raised by at least 10% and up to 30% in all ranges, and the maximum thermal efficiency of the engine itself has been improved by 20 to 30%[1].

2. 2. 5. Suzuki

The newly developed 1.4-liter 4-cylinder turbocharged K14C (Fig. 6), installed in the Escudo compact SUV, was launched in July. It is a direct injection engine equipped with a 4-1 merged headers exhaust manifold integrated in the cylinder head and a single-scroll turbocharger. The new Swift Sports launched in September uses the same engine with further improved output. Normal close control is applied to the wastegate to enhance the response to accelerator operation, enabling 0.17 seconds faster response time at 2,000 rpm[1].

2. 2. 6. Mitsubishi

The newly developed 1.5-liter 4-cylinder turbocharged 4B40 engine was installed in the Eclipse compact SUV

Table 2 Main new engines in North America in 2017

Manufacturers	Engine model*1	Cylinder arrangement	Bore × stroke (mm) (S/B ratio (–))	Displacement (cc)	Compression ratio (–)	VVT valve train*2 specifications IN/EX	Intake system	Fuel injection system*3	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Characteristics
Ford	99 F	V8	ϕ93.0 × 92.7 (1.00)	5,034	12.0	DOHC 4-valve Roller rocker Hydraulic/ hydraulic	NA	S-DI+PFI	343/7,000	569/4,600	Mustang GT (Conv.)	Spray-on bore liner, equipped with DI + PFI (Ford first)
	99 G	V6	ϕ92.5 × 86.6 (0.94)	3,496	10.5	DOHC 4-valve Roller rocker Hydraulic/ hydraulic	TC	S-DI+PFI	279/5,000	637/3,500	F-150 (Conv.)	Twin turbochargers, equipped with DI + PFI (Ford first), electric WGV (Ford first)
					10.0				335/5,000	691/3,500	F-150 Raptor (Conv.)	
	99 B	V6	ϕ90.4 × 86.6 (0.96)	3,337	12.0	DOHC 4-valve Direct tappet Hydraulic/ hydraulic	NA	S-DI+PFI	216/6,500	359/4,000	F-150 (Conv.)	Equipped with DI + PFI (Ford first)
	99 P	V6	ϕ83.0 × 83.0 (1.00)	2,687	10.3	DOHC 4-valve Roller rocker Hydraulic/ hydraulic	TC	S-DI+PFI	242/5,000	542/2,750	F-150 (Conv.)	Variable displacement oil pump, twin turbochargers, equipped with DI + PFI (Ford first), HPL cooled EGR (EcoBoost first)
	Undisclosed (1.0-liter EcoBoost 3-cylinder) (Not released)	L3	ϕ71.9 × 82.0 (1.14)	999	10.5	DOHC 4-valve Roller rocker Hydraulic/ hydraulic	TC	C-DI (25 MPa)	63	Undisclosed	Focus (Conv.)	High tumble port, exhaust manifold integrated in head (3-1 merged headers), cylinder deactivation (#1 deactivated, deactivatable roller finger follower (DRFF)) (Ford first), cam #1J rolling bearing, pistons with cooling channels, dual turbine pin clutch discs, block coolant stoppage during warm-up (thermo switching), equipped with a gasoline particulate filter (GPF) since Euro 6 c.
									75			
									93			
	Undisclosed (1.5-liter EcoBoost 3-cylinder) (Not released)	L3	Undisclosed	1,500	10.5	DOHC 4-valve Roller rocker Hydraulic/ hydraulic	TC	C-DI+PFI	112	290	Fiesta ST (Conv.)	Exhaust manifold integrated in head (3-1 merged headers), cylinder deactivation (#1 deactivated, DRFF), GPF
									136			

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*3 : S-DI and C-DI represent, respectively, side and center layout direct injection, and the figure in parentheses indicates the direct injection maximum fuel pressure.

first launched in Europe in October before the introduction to Japan in March 2018. It includes a 4-1 merged headers exhaust manifold integrated in the cylinder head, inclined turbine housing, and electric wastegate valve. A hollow-head sodium filled valves, and a fuel system with both side layout direct injection and port fuel injection have been installed, providing powerful acceleration and high combustion efficiency(1).

3 North America

3. 1. Overview

Sales of new vehicles in the U.S. were 17.2 million vehicles, a 1.8% decrease compared to 2016, but sales of pickup trucks and SUVs remained strong. Automakers have been upgrading the large displacement engines for pickup trucks, as well as expanding the use of turbocharged downsized engines in the light-duty SUV class, to comply with corporate average fuel economy (CAFE) regulations. At the same time, stop-start systems are increasingly being made standard equipment.

3. 2. Trends of Each Manufacturer

Table 2 lists the new engines launched or announced by manufacturers in North America in 2017, which are summarized below.

3. 2. 1. Ford

The newly developed 3.3-liter V6 99B NA engine (Fig. 7) and the second-generation EcoBoost 2.7-liter V6 turbocharged 99P and EcoBoost 3.5-liter V6 turbocharged 99G, installed in the F-150 pickup truck in June, and the upgraded 5.0-liter V8 99F NA engine installed in the Mus-

Fig. 7 Ford 99B

tang GT in autumn, were launched. All of them represent Ford's first use of a fuel system with both direct and port fuel injection, and feature improved output and thermal efficiency[1]. Among engines not yet available, a technical paper was published on the second-generation EcoBoost 1.0-liter engine announced as the world's first 3-cylinder engine equipped with a cylinder deactivation system (scheduled for installation in the new hatchback Focus in 2018). The paper revealed that cylinder deactivation provide a -40 g/kWh decrease in fuel consumption in the 1,500 to 3,000 rpm light load range compared to the first generation model under the same operating conditions, and that the cooling system had been extensively modified to reduce fuel consumption[6]. A newly developed dual-mass flywheel and clutch disc reduce vibrations to solve the issue of NVH caused by engine speed 0.5th-order vibrations generated by uneven combustion intervals[7]. The installation of a newly developed 1.5-liter 3-cylinder EcoBoost engine equipped with the same cylinder deactivation in the Fiesta ST planned for release in 2018 was announced in February. That same engine is also scheduled to be installed in the new Focus hatchback to be launched in 2018[1].

4 Europe

4. 1. Overview

Thanks to economic recovery, new vehicle sales in Europe (within EU nations) increased by 3.4% over 2016 to reach 15.14 million vehicles, exceeding the 15 million mark for the first time in ten years. Factors such as restrictions on the entry of diesel vehicles in cities have increased the proportion of gasoline-engine based vehicles, sales of which exceeded those of vehicles with diesel engines for the first time in eight years. The proportion of HEVs has also risen, and an increase in the introduction of electric-powered vehicles such as 48 V mild HEVs and plug-in hybrid electric vehicles (PHEVs) has been observed. Turbocharged downsized engines remain mainstream, and incorporate further technological improvements such as the Miller cycle, variable turbine geometry (VTG) turbochargers, and high-pressure direct injection. Modularization is also seen in trends such as offering a lineup of engines with the same stroke/bore ratio for a different number of cylinders or the use of the same bore and stroke for both gasoline and diesel engines.

4. 2. Trends of Each Manufacturer

Table 3 lists the new engines launched or announced by manufacturers in Europe in 2017, which are summarized below.

4. 2. 1. Daimler

Newly developed 2.0-liter 4-cylinder and 3.0-liter 6-cylinder turbocharged engines, as well as an upgraded 4.0-liter V8 turbocharged engine, were introduced. All three models have many points in common, including the center layout direct injection with a ϕ 83.0 mm bore × 92.0 mm stroke and maximum fuel pressure of 20 MPa and CAMTRONIC (switching between two cam lobes)system[1]. The 2.0-liter 4-cylinder turbocharged M264 engine, installed in the Mercedes-Benz E350 48 V mild hybrid, was launched in October. It is equipped with where world's first 48 V water pump and a belt driven starter generator (BSG), and the CAMTRONIC system uses the Miller cycle for switching[8]. The 3.0-liter 6-cylinder turbocharged M256 (Fig. 8), installed in the Mercedes-Benz S500 mild hybrid, was launched in July. It replaces the 3.0-liter V6 M276 and is the first in-line 6-cylinder model since the M104 was discontinued in 1997. In addition to the electric water pump, it features an integrated starter generator (ISG) directly linked to the crankshaft, and the electric assist charger and electric AC compressor have been switched to 48 V. The CAMTRONIC system is used to change the timing of the closing of the intake valve[9]. The 4.0-liter V8 turbocharged M176 was installed in the S560 launched in July. This engine uses the CAMTRONIC system to perform cylinder deactivation[1]. The 1.4-liter 4-cylinder turbocharged M282 (Fig. 9), to be installed in the Mercedes-Benz A200 scheduled for release in the fourth quarter of 2018, has been announced. Jointly developed with Renault-Nissan, this engine features extremely compact triangular cylinder heads dubbed

Table 3 Main new engines in Europe in 2017

Manu-facturers	Engine model*1	Cylinder arrangement	Bore × stroke (mm) (S/B ratio (–))	Displacement (cc)	Compression ratio (–)	VVT valve train*2 specifications IN/EX	Intake system	Fuel injection system*3	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Characteristics
Daimler	M264	L4	ϕ83.0 × 92.0 (1.11)	1,991	10.0	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	C-DI (20 MPa)	220/5,800–6,100	400/3,000–4,000	E350 Coupé (mild HEV)	"Trumpet honig" bores, pressure-regulated oil pump, 48 V electric WP (world first), electric WGV, belt driven starter generator, Euro 6. Common to M264 and M256 High tumble port, plastic mounts, hollow-head sodium filled valves, Miller cycle (early intake closing, CAMTRONIC (switching between two cam lobes)), pistons with cooling channels, twin-scroll turbocharger (1–3, 4–6 in M256), piezo injectors, GPF.
	M256	L6	ϕ83.0 × 92.0 (1.11)	2,999	10.5	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	C-DI (20 MPa)	320/5,900–6,100	520/1,800–5,500	S500 (mild HEV)	Twin wire arc-sprayed (TWAS) bore coating (without steel liners), tumble and swirl used at low lift (asymmetric lift curve), two-path lubrication system (system with separate low and high pressure lubrication), 48 V electric WP, AC, and integrated starter generator (ISG), electric auxiliary charger, M10 spark plugs.
	M176	V8	ϕ83.0 × 92.0 (1.11)	3,982	10.0	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	C-DI (20 MPa)	345/5,250–5,500	700/2,000–4,000	S560 (Conv.)	NANOSLIDE (mirror finish) bores (without steel liners), cylinder deactivation (#2, 3, 5, and 8 deactivated, CAMTRONIC), two-stage variable oil pump, timing chain driven water pump, twin turbochargers (exhaust between banks), piezo injectors.
	M282 (Not released)	L4	ϕ72.2 × 81.4 (1.13)	1,332	10.6	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	C-DI (25 MPa)	120/5,500	250/1,620–4,000	A200 (Conv.)	Joint Renault-Nissan development, exhaust manifold integrated in head (4-3 merged headers), delta cylinder heads, bore spray coating + NANOSLIDE bores (without steel liners), Eco Tough coating on piston skirts, cylinder deactivation (#2 and 3 deactivated, CAMTRONIC (cam lobe switching)) (first in Mercedes-Benz 4-cylinder engines), two-stage variable oil pump, electronic thermostat calibrates exhaust emissions at a maximum of 950℃, GPF.
Renault	H5Ht 450 (Not released)	L4	ϕ72.2 × 81.2 (1.12)	1,330	10.5	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	C-DI (25 MPa)	85/4,500 103/5,000 120/5,500	220/1,500 240/1,600 270/1,800	Scénic (Conv.)	Renault-Nissan and Mercedes-Benz joint development, bore spray coating + NANOSLIDE bores (without steel liners)

Table 3 Main new engines in Europe in 2017 (cont.)

Manufacturers	Engine model*1	Cylinder arrangement	Bore × stroke (mm) (S/B ratio (–))	Displacement (cc)	Compression ratio (–)	VVT valve train*2 specifications IN/EX	Intake system	Fuel injection system*3	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Characteristics
VW	EA211 TSI evo	L4	ϕ74.5 × 85.9 (1.15)	1,498	12.5	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	S-DI (35 MPa)	96/5,000–6,000	200/1,400–4,000	Golf (Conv.)	96 kW specifications only : Miller cycle, variable turbine geometry (VTG) turbocharger, exhaust emissions calibrated to a maximum of 880℃. Common to 96 and 110 kW specifications : Exhaust manifold integrated in head (4-1 merged headers), dummy head honing, cylinder deactivation (#2 and 3 deactivated, ACT evo (switching between two cam lobes)), coolant stoppage during warm-up (map controlled cooling module), common rail system. 110 kW specifications only : Plasma spray-coated bores (without steel liners), sodium filled valves, electric WGV, exhaust emissions calibrated to a maximum of 1,050℃, λ = 1 in all ranges.
					10.5				110/5,000–6,000	250/1,500–3,500		
Audi	EA839 2.9 TFSI	V6	ϕ84.5 × 86.0 (1.02)	2,894	10.0	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	C-DI (25 MPa)	331/5,700 – 6,700	600/1,900 – 5,000	RS5 Coupé (Conv.)	Twin turbochargers (exhaust between 90° banks), maximum boost pressure of 1.5 bars.
	EA839 3.0 TFSI	V6	ϕ84.5 × 89.0 (1.05)	2,995	11.2	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	C-DI (25 MPa)	260/5,400 – 6,400	500/1,370 – 4,500	S4 (Conv.) SQ5 (Conv.)	Common to 2.9 - and 3.0 -liter specifications Exhaust manifold integrated in head (3-1 merged headers), thin 1.5 mm steel liners, Miller cycle (early intake closing, Audi Valvelift System (AVS): switching between two cam lobes), split cooling. Swirl combustion, full variable capacity oil pump, coolant stoppage during warm-up, twin-scroll single turbocharger (exhaust between 90° banks), 48 V compatible
Porsche	DGP-EAP	V6	ϕ84.5 × 86.0 (1.02)	2,894	10.5	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	C-DI (25 MPa)	243/1,750 – 5,000	450/5,250 – 6,500	Panamera 4 E-Hybrid (PHEV)	Exhaust manifold integrated in head (3-1 merged headers), Miller cycle (early intake closing, VarioCam Plus: switching between two cam lobes), twin turbochargers (exhaust between 90° banks).
Jaguar Land Rover	AJ20 -P4 Mid	L4	ϕ83.0 × 92.0 (1.11)	1,997	10.5	DOHC 4-valve Roller rocker Hydraulic/hydraulic	TC	C-DI (25 MPa)	147, 184/5,500	340, 365/1,300 to 4,500	XE (Conv.)	Modular design shared with Ingenium diesel engines. Common to mid and high specifications: High tumble concept, low S/V ratio combustion chamber, exhaust manifold integrated in head (4 -2 merged headers), Miller cycle (early intake closing, hydraulically driven stepless variable lift), thin press-fitted liner, rolling bearing camshaft at exhaust, sodium filled valves, fully variable oil pump, split cooling, coolant stoppage during warm-up, fully variable WP, twin-scroll turbochargers, Euro 6 c. High specifications only : Ball bearing turbocharger
	AJ20 -P4 High				9.5				221/5,500	400/1,500 to 4,500	XE (Conv.)	

*1 : Engines announced between January and December 2017 but not yet on sale are indicated as "not released".
*2 : In this article, VVT is used as a unified designation for camshaft position variable mechanisms.
*3 : S-DI and C-DI represent, respectively, side and center layout direct injection, and the figure in parentheses indicates the direct injection maximum fuel pressure.

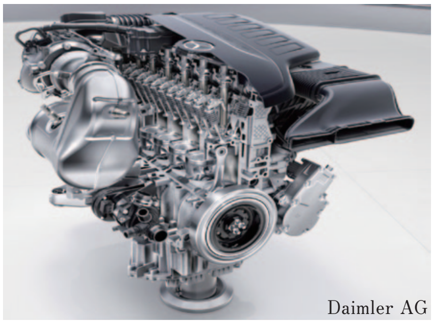

Fig. 8 Daimler M256

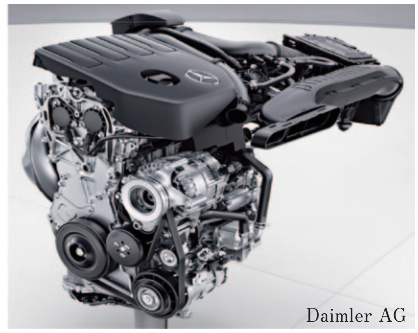

Fig. 9 Daimler M282

Fig. 10 VW EA211 TSI evo

delta cylinder heads, and the application of bore spray coating (BSC) and NANOSLIDE (a mirror finish) to the cylinder bores, along with the first use of cylinder deactivation via CAMTRONIC in a 4-cylinder engine by Mercedes-Benz, make this engine stand out. At Mercedes-Benz, it replaces the 1.6-liter 4-cylinder turbocharged M270 engine.

4. 2. 2. Renault

The 1.3-liter 4-cylinder turbocharged H5Ht 450 jointly developed with Daimler was announced in December. It will be installed in the new Scénic MPV to be released in January 2018. It is based on the Daimler M282 described above, but offers three different output variations. All specifications use the bore spray coating technology found in the Nissan GT-R VR38DETT engine[1]. The stroke, displacement, and designations (1.3-liter/1.4-liter) presented in this article respect those respectively announced by Daimler and Renault.

4. 2. 3. Volkswagen

The EA211 TSI evo 1.5-liter 4-cylinder engines (Fig. 10) with 110 kW specifications and 96 kW specifications were installed in the Golf and launched, respectively, in March and August. In a manner comparable to the Audi concept of rightsizing, which involves balancing fuel consumption and output through measures such as incorporating cylinder deactivation while maintaining a suitable displacement[1], the displacement of the previous EA211 1.4-liter TSI model has been increased by 0.1 liters, and a cylinder deactivation system has been equipped. To raise production line efficiency, the manufacturer announced that with the transition of the EA211 series to the upcoming eco series, the current displacement range of 1.0 to 1.6 liters for NA engines, and 1.0 to 1.4 liters for turbocharged engines, would both be limited to the two categories of 1.0 and 1.5 liters. The newly released 1.5-liter 110 kW specifications engine uses sodium filled valves and calibrates the maximum exhaust temperature to 1,050° C to achieve an excess air ratio of $\lambda=1$ in all ranges. Plasma spray-coated bores have been used to accommodate the maximum cylinder pressure of 13.5 MPa. The 96 kW specifications engine adopts the Miller cycle to achieve a compression ratio of 12.5 even with turbocharging. It is also equipped with a VTG turbocharger that reduces fuel consumption by about 10% compared to the previous model. Both variations share a 4-1 merged headers exhaust manifold integrated in the cylinder head, heat management system that stops coolant flow during warm-up, and a 35 MPa direct injection system[11].

4. 2. 4. Audi

A newly developed 2.9-liter V6 turbocharged engine in the EA839 series (Fig. 11), installed in the RS5 sports coupe, was launched in June. It represents a high-performance version of the EA839 3.0-liter engine mounted in the S5 coupe launched in September 2016, with twin turbochargers replacing the single turbocharger and a lower compression ratio. Due to the higher stress resulting from the increased output, the stroke was decreased by 3 mm and displacement was reduced by 0.1 liters. Although equipped with shared technologies that include the exhaust manifold integrated in the cylinder head, the Miller cycle using the intake Audi Valvelift System (AVS: switching between two cam lobes), split cooling, and twin turbochargers set between banks of 90 degrees. the new model also features frame modifications such as expanding the crankshaft main journal diameter by 2 mm. While this engine is developed and manufactured by Audi, Porsche has developed an engine based on it and preceded Audi by installing it on the Panamera 4S sports sedan launched in November 2016.

4. 2. 5. Porsche

The 2.9-liter V6 turbocharged DGP-EAP engine was

Fig. 11 Audi EA839 2.9 L

installed in the Panamera 4E-Hybrid PHEV launched in April. It is a model with lower output specifications than the newly developed 2.9-liter V6 turbocharged engine installed on the Panamera 4S conventional vehicle launched in November 2016. The turbocharging and other systems are proprietary Porsche developments that differ from those of the Audi EA839 2.9-liter engine[1].

4. 2. 6. Jaguar Land Rover

The newly developed Ingenium family 2.0-liter 4-cylinder turbocharged AJ20-P4 (Fig. 12), installed in the XE sports saloon and other models, was launched in May. It shares a modular design with the Ingenium 4-cylinder diesel engines launched in 2015 and 2016, with many common specifications and parts, including the bore diameter, stroke, and deck height, as well as the crankshaft main journal diameter, balancer position, gears, and the oil pan. The engine comes in two different hardware configurations, the mid and high specifications, with the mid specification further offering two output variations, for a total of three variations covering an output range of 147 to 221 kW. Both the mid and high specifications include high tumble combustion, the Miller cycle, an exhaust manifold integrated in the cylinder head, stepless intake variable valve lift, sodium filled valves, coolant stoppage during warm-up, full variable oil and water pumps, and twin-scroll turbochargers, with the high specification adopting a ceramic roller bearing turbocharger. The engines comply with the emissions regulations of various countries and have reduced fuel consumption[1][12].

Fig. 12 Jaguar AJ20-P4

5 Trends in Research

5. 1. Government-Industry-Academia Collaboration

The Innovative Combustion Technology project of the Cross-ministerial Strategic Innovation Promotion Program (SIP) initiated in 2014 entered the fourth year of its 5-year plan, leading to a succession of reports on research outcomes[13]. Research on the super lean burn concept targeting a 50% thermal efficiency had achieved brake thermal efficiency equivalent to 44.4% at the end of the 2016 fiscal year. The main research outcome in the field of model development, was the progress made on the HINOCA 3D engine combustion analysis software, which enables the prediction of not just average flow, but also of fluctuation between cycles, as well as the building of detailed reaction mechanism of surrogate gasoline that allow high accuracy predictions of combustion characteristics. In the field of actual measurements, micro particle image velocimetry (PIV) has been used to measure the flow areas in the vicinity of the wall surface near the top of pistons, revealing that the tumble flow boundary layer does not reach the boundary layer of the turbulence that has developed. Elsewhere, microelectromechanical systems (MEMS) technology has been applied to the development of technology that enables the measurement of thermal flux of multiple points with a high degree of accuracy.

5. 2. Fuel Technologies

Research on applying new fuel technologies to the reduction of engine CO_2 and other emissions is also underway. In Japan, research is being conducted on fuel characteristics that expand the combustion limit in lean burn combustion as well as that improve knock resistance, hinting at the potential of contributing to CO_2 reduction through a combination of engine and fuel technologies. In Europe, the reduction of well-to-wheel CO_2 emissions using such as the power-to-gas and power-to-liquid synthetic fuels produced by renewable energy is being studied.

At the same time, the U.S. Department of Energy and national laboratories are leading a research and development initiative for the co-optimization of fuel and engine technologies called Co-Optima. Such active research on the combination of fuel and combustion promises to further enhance the potential of engines.

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