# The MIRA Engine Review

***Sample Pages***

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# MITSUBISHI MOTORS

## Engine Development Strategy

### Overview

Innovative engine technology has long been considered a development priority at Mitsubishi. In particular the company has focused its efforts on producing more efficient engines which minimise their impact on the environment. Another key company goal has been to cut carbon dioxide emissions. Mitsubishi has thus set aside what it describes as "a significant amount of money" in order to further its engine development.

The company is leading the way in the development of lean-burn engines. Lean-burn engines are those that run on very weak mixtures, generally operating on air/fuel ratios of 20:1 or greater as against standard engines which work off air/fuel ratios of under 15:1. In October 1991 the company launched its 1.5 litre 3-valve Mitsubishi Vertical Vortex (MVV) engine for use in its Mirage/Lancer subcompact models. It followed this in October 1993 with its 1.8 litre 4-valve MVV engine which powered some Galant/Eterna models. Then in December 1994, Mitsubishi released details of the world's first lean-burn engine of over 2 litres - previously considered too daunting a challenge. The V6 2.5 litre 24-valve MVV engine was developed for use in its Diamante series of mid-sized sedans for the Japanese market.

In June 1995 Mitsubishi introduced the world's first in-cylinder direct injection (DI) petrol engine developed specifically for its Galant/Eterna series. Whilst the idea of in-cylinder DI is not new, this new generation engine technology has contributed to the development of more environmentally-friendly vehicles, as amongst other factors, the engine dramatically cuts carbon dioxide emissions.

Mitsubishi had two major objectives with regard to the direct injection petrol engine. These were as follows:

- Ultra low fuel consumption to exceed that of diesel engines - this has been achieved by stratifying the fuel combustion stroke. Stratification is itself achieved via an unique air flow which enables stable and complete combustion at the ultra-lean mixture ratio of 40:1.
- Superior power to that of conventional multi-port injection (MPI) engines - the company has done this by incorporating a high efficiency air-intake system which improves volumetric efficiency and increases the compression ratio.

### Mitsubishi Motors Environmental Action Programme

Since 1989, Mitsubishi has had in place a project team to co-ordinate its strategy with regard to environmental problems. In March 1993, the team (re-organised as a company-wide Environmental Council), drew up the Mitsubishi Motors Environmental Action Programme detailing the company's "philosophy for tackling general environmental problems". The third section of the Environmental Action Programme deals specifically with environmental issues related to the company's developmental activities (including their engine development work). Recent examples of the initiatives undertaken as part of the Environmental Action Programme include:

- Development and marketing of low-consumption engines (e.g. MVV engine).
- Development and marketing of ultra-low consumption, high output engine (e.g. GCI engine).
- Development of low-emission alternative fuelled vehicles (e.g. Libero EV, MBECS bus, CNG CANTER truck, LPG CANTER GUTS truck).

## R&D Expenditure

During FY 1997, Mitsubishi Motors spent approximately ¥140 billion ($1.1 billion) on research and development activities, approximately 3.8% of consolidated net sales. By comparison, each of Mitsubishi's major competitors invested significantly more on R&D during 1997. For example, Toyota spent an estimated ¥480 billion (~$3.87 billion) on R&D, whilst Honda and Nissan spent ¥268 billion ($2.16 billion) and ¥210 billion ($1.69 billion) respectively.

**Table 1: Mitsubishi Research and Development Spending (1992 - 1996)**

| ¥ millions | 1993 | 1994 | 1995 | 1997 |
|---|---|---|---|---|
| R&D expenditure | 127,000 | 122,000 | 132,000 | 140,000 |
| Consolidated Sales | 2,946,932 | 3,414,133 | 3,537,018 | 3,672,085 |
| % of Sales | 4.3 | 3.6 | 3.7 | 3.8 |

Source: Mitsubishi Motor Corporation

It has been reported that Mitsubishi and Volvo are considering investing approximately $885 million to jointly develop an advanced direct injection petrol engine. (For more information please refer to the Joint Ventures/Alliances section below)

## R&D Facilities

Mitsubishi operates three principal research and development centres in Japan, and two R&D centres overseas (Illinois, USA and Hessen, Germany). The company's engine development work is conducted primarily at its "Kyoto Zone" facility, as part of its Passenger Car Engineering Center. Mitsubishi also conducts engine development work for commercial vehicles (including trucks and buses) at its "Maruko Zone" facility located in Tokyo.

**Table 2: Mitsubishi Engine-Related R&D Facilities (1997)**

| Facility | Location | Activities |
|---|---|---|
| Passenger Car Engineering Center (Okazaki Zone) | Okazaki, Aichi | basic research, product development |
| Passenger Car Engineering Center (Kyoto Zone) | Kyoto, Shiga | engine R&D |
| Truck and Bus Engineering Center (Kawasaki Zone) | Kawasaki, Kanagawa | basic research, product development |
| Truck and Bus Engineering Center (Maruko Zone) | Ohta, Tokyo | engine R&D |

Source: Mitsubishi Motor Corporation

## Engine Production Facilities

Mitsubishi's Kyoto plant is responsible for nearly 60% of the company's total engine production, accounting for more than 2 million units in 1996. The Mizushima plant produces approximately 350,000 engines for minicars per year, whilst its Shiga plant produces about 260,000 passenger car engines annually. Mitsubishi's large engines (for commercial vehicles) are produced at its Kawasaki facility located near Tokyo.

Overseas, Mitsubishi has facilities to build or assemble engines in the United States, Australia, Indonesia, and since mid-1997 in the Philippines.

**Table 3: Mitsubishi Engine Production Facilities (1997)**

| Plant | Location | Production |
|---|---|---|
| Kyoto Plant | Kyoto, Shiga | passenger car engines (GDI engines) |
| Shiga Plant | Kosunacho, Shiga | passenger car engines |
| Mizushima Facility | Kurashika, Okayama | engines for minicars |
| Kawasaki First Plant | Nakahara, Kawasaki | truck and bus engines |
| Mitsubishi Motor Manufacturing America (MMMA) | Normal, Illinois (USA) | V-6 engines |
| Mitsubishi Motors of Australia | South Australia | V-6 engines, cast parts |
| P.T. Mitsubishi Krama Yudha Motors and Manufacturing | Jakarta, Indonesia | engines, stamping parts |
| Asian Transmission Corp. | Philippines | engines & transmissions (began operations in mid-1997) |

Source: Mitsubishi Motor Corporation

### Construction Of New Plant In Japan

In August 1997, Mitsubishi began construction of a new plant located in Yagi-cho (Kyoto prefecture) to manufacture direct injection petrol engines and continuously variable transmissions. Full production is expected to commence in early 1999, with an initial capacity of approximately 24,000 units/month. Total investment in the facility is expected to be around ¥23 billion ($184 million).

### Engine Production Joint Ventures In China

In August 1996 Mitsubishi announced that it had agreed to form two engine production joint ventures in China. The first, known as Harbin Dong-An Mitsubishi Motors Engine Manufacturing Co. will produce 1.3 litre engines and transmissions beginning in 1998. Within five years, annual capacity of engines and transmissions is expected to reach 150,000 units each. Mitsubishi will hold a 25% stake in the venture, which is capitalised at ¥8.5 billion ($68 million). The other participants in the joint venture include: Harbin Dong-An Engine Manufacturing Co. (36%); Harbin Aircraft Mfg. Co. (15%); Mitsubishi Corp. (9.3%); and MCIC (Malaysia China Investment Corp.) Holdings Sdn. Bhd. (14.7%).

The second venture, known as Shenyang Aerospace Mitsubishi Motors Engine Manufacturing Company is scheduled to begin production of 2.0 and 2.4 litre engines and transmissions in 1999. Located in Shenyang (Liaoning Province), this venture is capitalised at ¥8.76 billion ($71 million) with Mitsubishi again holding a 25% stake.

Mitsubishi Corp. (9.3%) and MCIC Holdings (14.7%) are also partners in this joint venture, with China Aerospace Automotive Industry Group Corp. (30%) and Shenyang Construction Investment Corp. (21%) the local partners.

## Joint Ventures/Alliances

Mitsubishi has a large network of co-operative agreements with other vehicle manufacturers for joint production and/or development of both vehicles and engines. In fact, Mitsubishi Motors (often in co-operation with its parent Mitsubishi Corporation) holds an ownership stake in a number of “middle tier” OEMs such as Hyundai (approximately 15%), and Proton (approximately 30%). In addition to these equity-based arrangements, Mitsubishi has engine-related alliances with Chrysler, Mazda, Renault, and Volvo as outlined below.

### Relationship With Chrysler

Chrysler and Mitsubishi have been working co-operatively since 1971 when the American firm purchased a 20% stake in the Japanese manufacturer. Although Chrysler’s ownership reached a peak of 24% (in 1985), their ownership in the company declined throughout the late 1980s and early 1990s. In July 1991, Chrysler sold its 50% stake in the companies’ American joint-venture Diamond Star Motors, and in July 1993 Chrysler ended its equity participation in Mitsubishi when it sold its remaining 2.7% stake.

Since 1994, Mitsubishi’s Diamond-Star venture (renamed Mitsubishi Motor Manufacturing America) has bought Chrysler-made engines and transmissions for its Galant model in the United States (approximately 60,000 in 1994). In return, Mitsubishi supplies Chrysler with approximately 430,000 engines a year (including its V-6 engine) from its Kyoto plant, in a deal which is scheduled to end in 1999. Chrysler and Mitsubishi also co-operate in the design, production and distribution of vehicles and components.

### Production Joint Venture With Volvo

Mitsubishi and Volvo each control 33.3% of a joint venture production company in the Netherlands known as Nederland Car BV (Ned Car). The Dutch government, which holds the other 33.3% share is scheduled to sell its interest in the venture to both Volvo and Mitsubishi in 1998.

The two companies are set to expand their existing relationship, by beginning the co-development of engines and possibly even a shared platform for passenger cars. Mitsubishi and Volvo believed to be undertaking a feasibility study to determine whether they will jointly invest up to $885 million to develop an advanced direct injection petrol engine, based on Mitsubishi technology.

Mitsubishi will supply Volvo with 1.8 litre GDI engines (from Kyoto) for use in the Swedish company’s S40 and V40 models produced at their Ned Car joint venture plant in Born (the Netherlands). The GDI equipped Volvos are expected to make their debut in March 1998. Mitsubishi is also expected to provide Volvo with technical assistance for its direct injection petrol engines.

### Relationship With Hyundai

Mitsubishi Motors and Mitsubishi Corp. own approximately 15% of Hyundai Motors. In addition, Mitsubishi provides Hyundai with both technical assistance and finished products (such as engines and transmissions). Hyundai also produces a number of vehicles based on Mitsubishi designs.

It has been reported that Hyundai and Mitsubishi are currently co-developing a V8 powered luxury car, which is expected to be launched by the year 2000. Additionally, the two company's have signed a memorandum of understanding to begin a full-scale feasibility study into even more joint development work, which is said to include a new range of V6 and V8 engines. At the present time, neither Mitsubishi nor Hyundai produce an engine that is larger than 3.5 litres in capacity.

Mitsubishi is also expected to supply Hyundai with its GDI direct injection engine.

### Engines From Renault

Renault supplies engines (e.g. 1.9 litre diesel engine) and transmissions to Mitsubishi's European joint venture (Ned Car) with Volvo in the Netherlands.

### Component Supply To Mazda In Indonesia

Mitsubishi supplies Mazda's Indonesian subsidiary with engine components for its commercial vehicle operation.

# Recent Engine Developments

## Overview

Much of Mitsubishi's recent engine development work has centred around the commercialisation of its much heralded gasoline direct injection (GDI) engines. In mid-1996, Mitsubishi became the first automaker to introduce a direct injection petrol engine for mass production, its 1.8 litre GDI. In the first 6 months after its launch in August 1996, Mitsubishi sold more than 60,000 GDI equipped Galant/Legunam models, and is currently expanding its Kyoto plant to meet increased demand for the units.

As part of its long term strategy Mitsubishi intends to phase out its lean burn technology in favour of its direct injection system. In order to offset the high development costs associated with its GDI technology, the company intends to offer a range of GDI engines from 1.8 litres to 3.5 litres. In April 1997, the company released details of its second GDI variant, a 3.5 litre V-6 design, and it is now undertaking development on a further two GDI engines: a 2.0 litre powerplant; and a 3.0 litre unit. In fact, according to Mitsubishi sources, all of the company's petrol engines are potential candidates for conversion to GDI technology, with the exception of its 660 cc minicar engine (which is too small to reap the full benefits of GDI).

Commenting on the release of Mitsubishi's DI petrol unit, the Austrian engine specialist AVL believes that it will be an essential engine for the future due to ability to offer the fuel consumption of an indirect injection diesel with the weight and performance characteristics of a petrol engine.

## Gasoline Direct Injection (GDI) Engines

Although each of Mitsubishi's GDI variants have characteristics specific to that particular engine, the basic technology behind the design of the engines is common. Perhaps the most important driving force behind Mitsubishi's development of this technology, was its ability to tightly control the combustion of an extremely lean air/fuel mixture. Other important developments in Mitsubishi's GDI engines include:

- Pistons which feature a deep-bowl curved-top crown for better combustion.
- Radically altered intake ports to ensure that air entering the combustion chamber is directed vertically downwards for optimal airflow control in the cylinder.

As a result of these alterations, the GDI engines achieve significant improvements in fuel efficiency, power, torque and reduced emissions of nitrogen oxides. At the present time, the only real drawbacks to this technology are its increased cost (approximately US $300 per unit), and the difficulties associated with reducing $NO_x$ emissions.

Some of the major features associated with Mitsubishi's GDI engine are discussed in the following section.

### Low Fuel Consumption

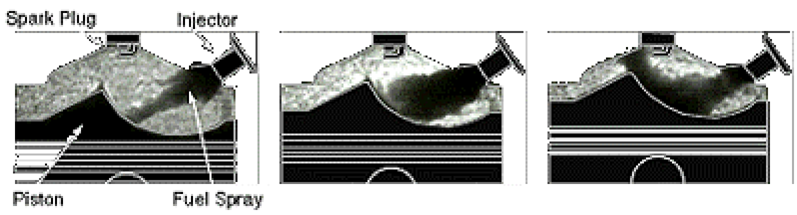
In order to achieve low fuel consumption, Mitsubishi aimed for ultra-lean combustion by stratifying the fuel in the cylinder in the final stages of the combustion stroke. This stratification was achieved by the generation of airflow which allowed stable and lean combustion at an ultra-lean mixture ratio of 40 to 1.

### Cylinder Air Flow

During the intake stroke, the upright straight intake port triggers a strong downward flow in the mixture, and in combination with the curved head piston forms a tumble which rotates in the opposite direction from that generated in a conventional engine. The tumble sends the spray, which is injected into the cylinder in the final stage of the compression stroke, to the centrally positioned spark plug at the moment of ignition. Mitsubishi's approach was to utilise a single injection with a pilot injection and a main jet. It is a not a spark-assisted compression engine.

### Fuel Spray Configuration

The new high-pressure swirl injector converts the fuel injected into the cylinder, in the final stage of the compression stroke, into a compactly shaped atomised spray. The actions of the tumble and curved head piston allow the spray to vaporise rapidly without diffusion and is transported to the spark plug in a stratified and mixed state. Whilst the air-fuel mixture in the combustion chamber is predominantly weak, its stratified and mixed state in the region of the spark plug causes it to be very rich so that it ignites readily to assume its stable combustion characteristics (See Figure 1).




Source: Mitsubishi Motors

**Figure 1: GDI Fuel Injection Pattern (during compression stroke)**

The manner of stratified combustion achieved allows stable combustion with an ultra-lean mixture at idling speeds where combustion is normally least stable, as well as at slower idling speeds. Consequently, there is a reduction in idling fuel consumption of around 40% over conventional engines, whilst consumption under normal driving conditions is reduced by nearly 25% at 40 km/h.

### Higher Power Output

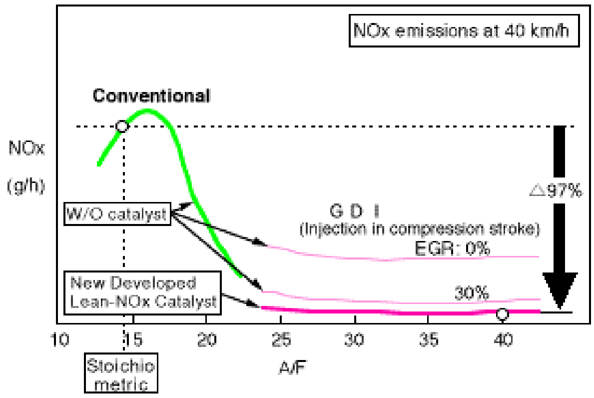
Power output has been increased through a combination of increasing volumetric efficiency and higher intake efficiency resulting from the use of a higher compression ratio.

### Raising Volumetric Efficiency

Two features have contributed to an increase in the volumetric efficiency of the DI engine under high load operation. These were: smoother intake airflow as a result of the upright straight intake port; and the pre-injection of fuel during the intake stroke. The latter results in a cooling of the intake air, and the subsequent rise in density is due to a reduction in the gas temperature which accompanies the heat loss when the fuel vaporises. Consequently, the new engine is able to achieve a significant increase in volumetric efficiency and in the amount of air drawn in at all engine speeds compared with conventional engines.

**Mitsubishi 1.8 litre DOHC GDI Engine (4G93 GDI)**

Mitsubishi's first mass produced gasoline direct injection, the 1.8 litre DOHC in-line four cylinder powerplant, is based on its conventional "4G93" multi-port injection engine. Although the basic dimensions of the GDI engine are identical to those of its predecessor, the new engine offers a 10% increase in performance along with a 35% improvement in fuel economy at 40 km/h (and a 40% increase in economy during idling). In addition, the use of high-rate EGR coupled with the development of a new lean-NOx catalyst, results in 97% reduction in NOx emissions.



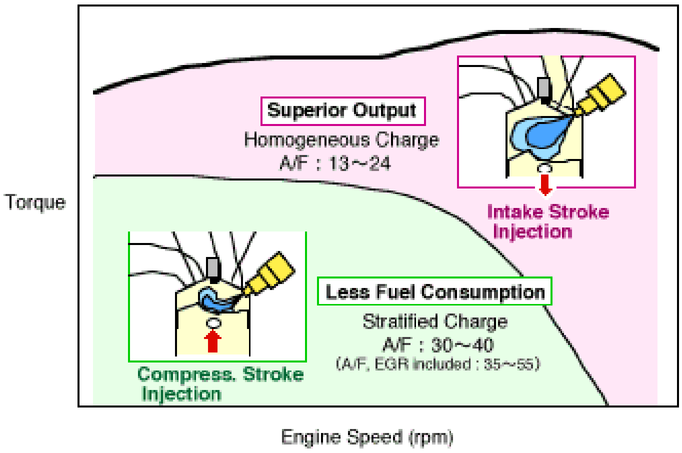

Source: Mitsubishi Motors Corporation

**Figure 2: Mitsubishi 1.8 Litre GDI - NOx Emissions**

The 1.8 litre GDI engine features:

- Upright straight intake ports for optimal airflow control in the cylinder.
- Curved-top pistons for better combustion.
- High-pressure swirl injectors for optimum air/fuel mixture.

The engine operates under two combustion modes, whereby the injection timing is changed to match engine load. Under "normal" driving conditions (up to speeds of 120 km/h), the engine operates in "Ultra Lean Combustion Mode", with fuel injection occurring at the latter stage of the compression stroke and ignition occurring at an air/fuel mixture between 30 and 40:1 (35-55:1 with EGR). During high performance conditions (at speeds above 120 km/h), the engine operates in "Superior Output Mode", with fuel injection occurring during the intake stroke, and ignition occurring close to stoichiometric mixtures (13-24:1). In this mode, the cooler, homogenous air fuel mixture optimises combustion and reduces the possibility of engine knocking.




Source: Mitsubishi Motors Corporation

**Figure 3: Mitsubishi 1.8 Litre GDI - Two Mode Operation**

**The specifications for Mitsubishi's 1.8 litre GDI engine are shown in the table below.**

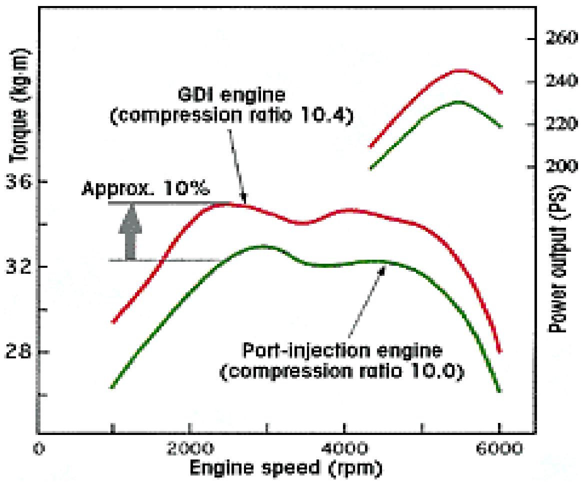
**Table 4: Mitsubishi 1.8 Litre Gasoline Direct Injection (GDI) Engine**

| | |
|---|---|
| Cylinders | In-line, 4-cylinder |
| Valve gear type | DOHC |
| Capacity (cc) | 1834 |
| Valves per cylinder | 2 inlet, 2 exhaust |
| Bore x Stroke (mm) | 81.0 x 89.0 |
| Combustion chamber | Pent roof (curved top piston) |
| Intake port | Upright Straight port |
| Fuel feed method | In-cylinder direct injection |
| Compression ratio | 12.0 |

Source: Mitsubishi Motors

**Mitsubishi 3.5 Litre V6 GDI Engine (6G74)**

In April 1997, Mitsubishi announced details of its second direct injection petrol engine, the 3.5 litre V-6 DOHC GDI engine. Compared with its port-injection model, the 3.5 litre GDI offers a 10% increase in power output, and a 30% reduction in $CO_2$ emissions, with a 30% improvement in fuel economy (See Figure 4). As a result, overall vehicle performance is also improved with the GDI-powered test vehicle accelerating from 60 to 80 km/h approximately 10% quicker than Mitsubishi's "conventional" 3.5 litre engine, and take-off response improving by 20%.




Source: Mitsubishi Motors Corporation

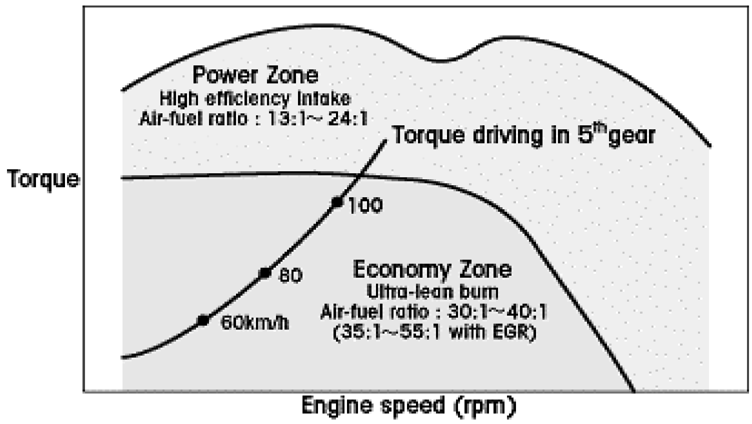
**Figure 4: Mitsubishi 3.5 litre GDI - Engine Performance**

Based on Mitsubishi's current 6G74 MPI engine, the new engine was developed with two principal aims:

1. Achieve ultra-low fuel consumption (i.e. better than diesel engines) and a reduction in $CO_2$ emissions.
2. Generate higher power output than equivalent port-injection engines.

In order to achieve these "conflicting" development aims, Mitsubishi's GDI system operates via two modes (See Figure 5):

- Economy zone - under normal operating conditions the engine runs on ultra-lean mixtures of between 30 and 40:1 (up to 55:1 when EGR is considered).
- Power zone - under higher engine loads (i.e. above 100 km/h) the engine switches to high efficiency intake with an air/fuel ratio of between 13 and 24:1 (i.e. stoichiometrically).




Source: Mitsubishi Motors Corporation

**Figure 5: 3.5 Litre GDI - Two Mode Operation**

In Mitsubishi's 3.5 litre GDI engine most of the major GDI components fit neatly between the cylinder banks, resulting in a more compact design than the conventional powerplant upon which it is based. The major differences between Mitsubishi's GDI engine and its multi-port counterpart include:

- Electronically controlled throttle valve - provides high precision control of the large volumes of air required to achieve "lean burn".
- Upright straight intake ports - control airflow into the cylinder.
- Curved-crown pistons - control combustion behaviour.
- High pressure fuel pump - injects fuel directly into cylinders under high pressure to ensure optimum combustion.
- High pressure swirl injectors - to atomise and disperse the high-pressure fuel injection spray.

**Table 5: Mitsubishi 3.5 litre Gasoline Direct Injection (GDI) Engine (6G74 GDI)**

| | |
|---|---|
| Cylinders | V-6 |
| Valve gear type | DOHC |
| Capacity (cc) | 3496 |
| Valves per cylinder | 2 inlet, 2 exhaust |
| Bore x Stroke (mm) | 93.0 x 85.8 |
| Combustion chamber | Curved Crown |
| Intake port | Upright Straight port |
| Fuel feed method | In-cylinder direct injection |
| Fuel feed pressure | 50 $kg/cm^2$ |
| Compression ratio | 10.4 |

Source: Mitsubishi Motors

**Mitsubishi 2.5 litre V-6 Lean Burn MVV (Mitsubishi Vertical Vortex) Engine (6G73)**

In 1995 Mitsubishi claimed a world first by developing a lean burn engine of greater than 2 litres when it introduced its 2.5 litre V6 MVV. This V6 engine was Mitsubishi's second-generation lean burn MVV unit, after its 1.5 litre 3 valve per cylinder engine which was launched in October 1991.

As Mitsubishi state in their publication Tech Express "The engine employs unique technology for lean-burn limit control of the air-fuel ratio. This technology makes use of the crank-angle sensor already mounted to control ignition timing. An automotive CPU is used to detect the combustion state in each of the six cylinders and perform control so that the air-fuel ratio is always close to the lean-burn limit. This CPU is capable of high-level 16-bit processing enabling detection at speeds of 10 to 20 milliseconds."

**Table 6: Mitsubishi 2.5 Litre Lean Burn MVV Engine**

| | |
|---|---|
| Valve configuration | V type, 6 cylinders, horizontally placed |
| Valve type | Roller rocker arm, SOHC |
| Capacity (cc) | 2497 |
| Bore x Stroke (mm) | 83.5 x 76.0 |
| Valves per cylinder | 2 intake, 2 exhaust |
| Combustion chamber | Pent roof (tumble control piston) |
| Fuel delivery system | ECI-Multi |
| Air-fuel mixture control sensor | Conventional oxygen sensor |
| Compression ratio | 9.5 |

Source: Mitsubishi Motors

The key feature of the MVV is that it induces two vertical vortices in the cylinders - one air and a second consisting of an air/fuel mix to promote stable lean burn combustion. As this technology does not require any special mechanisms and can be utilised at low cost, it can be applied over a wide range of models.

Its so-called Lean Burn Limit Control monitors combustion and controls the mix in each cylinder to stop it overstepping stable lean-burn limits. Carefully configured cylinder head and combustion chamber design have been adopted in order to ensure the correct flow condition. A special sensor gauges the rotational speed of the crankshaft and adjusts the air to fuel ratio so as to maintain it as close to the lean burn threshold as possible. This results in an improved air-fuel ratio of 22:1, compared with a ratio of 14.7:1 in a conventional engine. In addition, nitrogen oxide emissions are reduced by some 50%.

In the 24-valve MVV engine the inlet ports are fitted with directional bulkheads and a tumble control piston provides turbulence control for the air-fuel mixture. The MVV also utilises a new tumble system whereby vertical swirl intake characteristics in the combustion chamber help to achieve a stable combustion. A rich mixture is produced around the spark plug after the air-fuel mixture has been vertically tumbled into the chamber.

Mitsubishi claims that fuel economy is some 16% better than for conventional 2.5 litre DOHC engines, and compares favourably with the high fuel economy of 2 litre cars.

### Mitsubishi 2.8 Litre Diesel Engine (4M40)

In July 1996, Mitsubishi revamped its 2.8 litre diesel engine for use in its Pajero 4WD model. Originally launched in 1993, the 4M40 engine was originally developed to “achieve high performance, low noise, low exhaust gaseous emissions and reduced smoke”. Although satisfying these general requirements, Mitsubishi’s 2.8 litre turbo-diesel had lagged behind more recent competitive offerings from both Toyota and Isuzu (1KZ-TE and 4JG2 respectively). In order to address this imbalance, Mitsubishi has made a number of changes to its 4M40 engine which have resulted in an appreciable increase in overall engine performance, and a reduction in engine noise and vibration.

The revamped 4M40 turbocharged, intercooled diesel engine features enhanced electronic control, including the use of a high performance water temperature sensor, an intake temperature sensor, and a crank angle sensor. Other refinements include:

- Use of an electronically controlled fuel pump.
- Full balancing of the crankshaft.
- Number one compression ring has been moved 1.5 mm higher.
- The profile of the number 2 oil ring has been modified.
- The oil pan double damper has been changed to copper.
- A throttle body assembly has been installed.
- Valve timing has been changed.
- Existing turbocharger has been modified.

**Table 7: Mitsubishi 2.8 Litre Turbo-diesel Engine (4M40)**

| | |
|---|---|
| Engine Layout | 4 cylinder in-line OHC |
| Capacity | 2835 cc |
| Bore x Stroke (mm) | 95.0 x 100 |
| Compression Ratio | 21:1 |
| Maximum Output (kW) | 103 @ 4000 rpm |
| Maximum Torque (Nm) | 314 @ 2000 rpm |

Source: Mitsubishi Motors Corporation

As a result of these changes, engine performance in the low speed range has been significantly improved. Modifications to the turbocharger and the valve timing have helped increase the maximum output of the engine by some 11 kW, and improved maximum torque by nearly 20 Nm.

## Key Development Activities

### Overview

In April 1995, Mitsubishi delivered a pair of "hybrid electric" vehicles to the California Air Resources Board (CARB) for fleet testing through to September 1997. These vehicles, which combine battery, electric motor and ULEV petrol engine technology, are stretched versions of Mitsubishi's Chariot station wagon (sold outside Japan as the Expo and Space Wagon). Station wagons and utility vehicles are generally regarded as the most promising vehicles for the initial market launch of such vehicles, due to the space requirements for the system components.

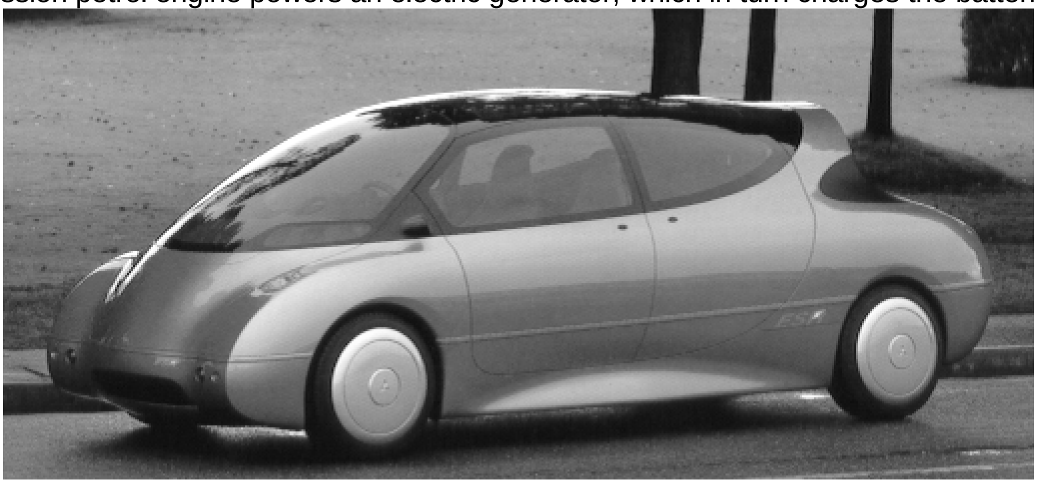
### Electric Vehicles

To date, Mitsubishi has produced over 150 electric vehicles (EV), of which nearly a third are still in active operation. The company's latest EV, is a modified version of its Libero estate vehicle, which was co-developed with the Tokyo Electric Power Company. The vehicle which is powered by Ni-Cd batteries has an effective range of 250 km and a top speed of 130 km/h.

### Ecological Science Research (ESR) Vehicle

Mitsubishi first displayed its Ecological Science Research (ESR) hybrid electric vehicle at the 1994 Tokyo Motor show (See Figure 6). This ultra-low emissions "concept" vehicle operates in two modes:

- Zero emissions mode - the vehicle runs on electric power stored in its batteries.
- Series hybrid mode - an emissions-free electric motor powers the vehicle (whilst a low emission petrol engine powers an electric generator, which in turn charges the batteries).



Source: Mitsubishi Motors Corporation

**Figure 6: Mitsubishi Ecological Science Research (ESR) Vehicle**

The ESR also features solar panels built into the roof to convert sunlight into electricity, which is then used to recharge the batteries as well as to ventilate the battery compartment.

Additionally, the ESR's motor generates energy by converting the kinetic energy of the vehicle's motion into electricity, which is also used to recharge the batteries.

**Hybrid Electric Vehicle (HEV)**

Building on its experience with its ESR vehicle, Mitsubishi has developed a second hybrid experimental vehicle which combines both electric and conventional powertrains. The Hybrid Electric Vehicle (HEV) automatically switches between battery and hybrid modes to provide "ecologically clean driving with efficient use of energy". The HEV uses only its batteries when operating in zero-emissions mode (for example, in urban driving). As the batteries begin to run down, the vehicle automatically switches to hybrid mode, with the HEV's low emission (compressed natural gas) engine recharging the batteries. As with the ESR, the HEV is also able to convert the vehicle's kinetic energy into electricity which is then used to recharge the batteries. The key characteristics of Mitsubishi's HEV are shown in the table below (See Table 8).

**Table 8: Mitsubishi Hybrid Electric Vehicle (HEV)**

| | |
|---|---|
| Battery (V / number) | 336V / 30 |
| Motor | A/C inductor (twin) |
| Maximum Output | 60 kW |
| Maximum Torque | 19.6 kgm |
| Layout | 4 cylinder, 1.5 litre |
| Fuel | Compressed Natural Gas |

Source: Mitsubishi Motors Corporation

**Natural Gas**

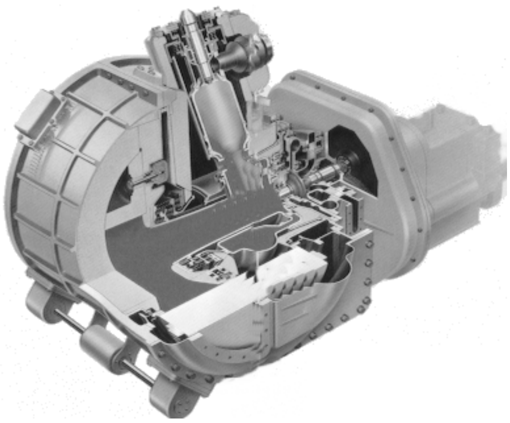
Mitsubishi views natural gas as a potentially viable long-term alternative to conventional fuels. Although natural gas engines generate about 30% less $CO_2$ than petrol engines, there are still a number of concerns regarding their practical use. For example, the current effective range of natural gas vehicles is only one fourth that of petrol engines due to the limited volume of gas which can be safely carried by the vehicle. Additionally, current technology available to liquefy the natural gas for transportation reduces the overall benefits of any $CO_2$ reduction. Finally, there are very serious safety concerns related to the storage of natural gas in high pressure fuel tanks on the vehicle. Mitsubishi is currently undertaking research into these problems, with a long-term view of creating a "viable alternative fuel vehicle".

**Ceramic Gas Turbine**

Mitsubishi has been involved in the development of turbine engines since the late 1960s. Although Mitsubishi's early metal turbine engines showed considerable promise (low polluting, high thermal efficiency, and adaptability to a variety of fuels), their high fuel consumption was unacceptable. In order to increase the fuel efficiency of the gas turbine engine, the company discovered that the turbine inlet gas temperature had to be increased beyond the capability of the metal. Thus, the company's research led to the development of highly heat-resistant ceramics, and in 1991 to the development of a "reliable" ceramic turbine rotor. In 1992, Mitsubishi was presented with the Japan Gas Turbine Society's Technical Award for its research on ceramic turbines.

In 1990, Mitsubishi, Toyota and Nissan in conjunction with the Japan Automobile Research Institute began a seven-year project to develop a ceramic gas turbine for automobiles. The project, conducted for the Petroleum Energy Centre, is sponsored by MITI in Japan.

In late 1996, the Petroleum Energy Centre released details of its ceramic engine development activities. The Centre has developed a 100 kW single-shaft regenerative engine having a turbine inlet temperature of 1350ºC and a rotor speed of 110,000 rpm. The engine components have been designed, experimentally evaluated and improved in both individual and various assembly test rigs. Additionally, an assembly test (including rotating and stationary components) has also been conducted under the condition of turbine inlet temperature of 1200ºC (See Figure 7).



Source: Mitsubishi Motors Corporation

**Figure 7: Petroleum Energy Centre's Ceramic Gas Turbine Engine**

### Methanol

Mitsubishi has been actively developing methanol-powered vehicles since the 1980s when it introduced a methanol/petrol passenger vehicle. The vehicle, which ran on a fuel mixture of 85:15 (methanol to petrol), was developed for a fleet test programme administered by MITI (the Japanese Ministry of International Trade and Industry). More recently the company has also developed a 100% methanol powered city bus for MITI's fleet testing programme.