CEC OACIS CRC

D.J. Smith
Barbican Technology
The Gate House
Aston Tirrold
Oxfordshire
England
OX11 9DJ

Phone / Fax: +44-1235-851554
E-mail: **barbican-technology@tiscali.co.uk**

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REPORT ON THE WORK OF THE CEC / CRC / OACIS TASK FORCE ON THE DEVELOPMENT OF A TEST METHOD TO EVALUATE FUEL QUALITY WITH RESPECT TO INJECTOR FOULING IN DIRECT INJECTION GASOLINE ENGINES

1. History

At the 2000 CEC Conference, held in Paris, there was all round support for the joint development of test procedures amongst regional bodies. It was felt that independent developments were leading to a multiplicity of tests, many of which measured the same properties and responded in the same manner to fuel and lubricant quality and additive treatment. The high cost of running and passing the majority of these tests in order to obtain global approval coverage was thought unnecessary and avoidable.

As a result, it was agreed to set up a working group supported by the Coordinating European Council (CEC) Europe, Coordinating Research Council (CRC) USA and the Oil and Automobile Cooperation for International Standards (OACIS) Japan to investigate ways of reducing the current test load and to coordinate future test developments.

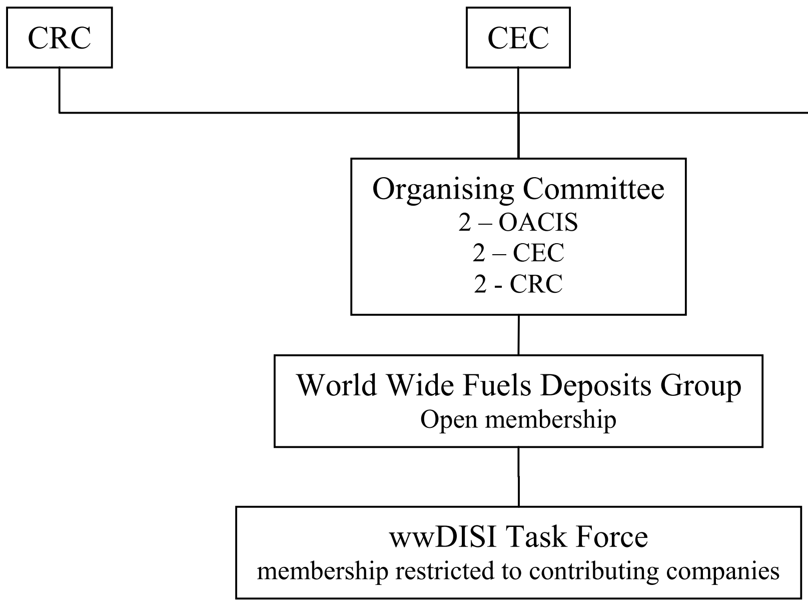
This working group recommended that obsolescing current tests was not a valid option because of the high investment that many companies held in these test results and the confidence that engine manufacturers and others had in their use. Instead, it was proposed that future test development should be organised on a regional basis, with regions pooling their resources on the development of a new test if it met their requirements.

The first opportunity for this occurred with the request for a fuel quality test on a direct injection gasoline engine.

The minutes of the inaugural meeting in Paris are presented in Appendix A.

2. Organisation

Although there was, at the time, only one test to be developed, a formal structure to protect the interests of the supporting organisations and to allow future development was established. This comprised three levels, the first of which was a committee of six with two representatives from each of the supporting organisations. To ensure as wide a support as possible, the level below this was open to any company representative from any country in the world with an interest in fuel and lubricant testing. Finally, a task force was established to develop the test. This was restricted to representatives from companies making a significant contribution to the test development programme.



3. Membership

Membership lists for each of the committees are presented in Appendix B

4. Basis of Test Method

In order to ensure that there was a real need to develop the test method, a literature search was conducted to surface supporting data. A number of papers were found which demonstrated the high levels of deposits found in direct injection gasoline engines, which were shown to differ in form, amount or responsiveness to those from conventional port fuel injected engines. The results of the search, which were delivered to the Deposits Group in May 2001, are presented in Appendix C.

Representatives from OACIS presented data in January 2002 on three engines from Mitsubishi, Nissan and Toyota, on which they had conducted some preliminary work. The details of these engines are shown below –

	Mitsubishi	***Nissan***	***Toyota***
Type	IL-4	IL-4	IL-4
Valve Train	D4	D4-CVTC	D4-VVTi
Displacement (cc)	1834	1998	1998
Bore x Stroke (mm)	81.0 x 89.0	89.0 x 80.3	86.0 x 86.0
Compression Ratio	12.0:1	10.5:1	9.8:1
Fuel Pressure (MPa)	5.0	3.0 – 11.0	8.0 – 13.0
Required RON	100 / 91	91	91
Regulation	J-2000	J-2000	J-TLEV
DeNOx Catalyst Type	Adsorbed		

Five Japanese fuels were tested, and the CRC and CEC members proposed two further fuels from each of these regions. The details are presented below.

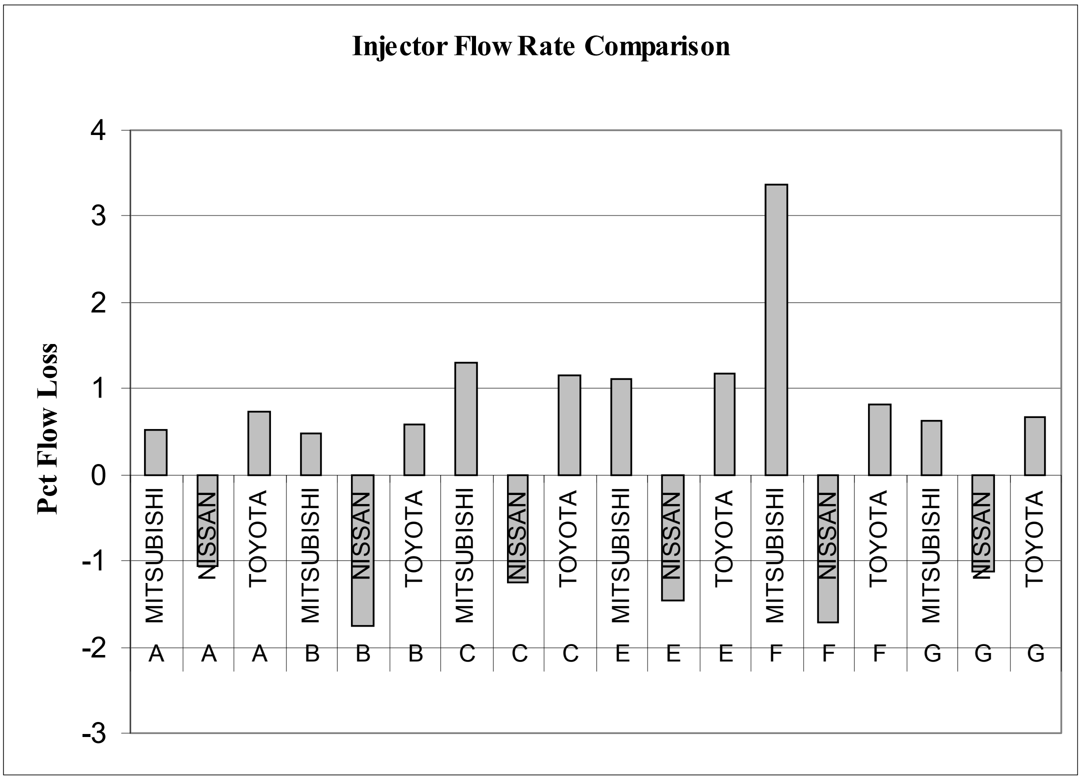
	A *Base*	*B*	*C*	*D*	*E*	*F* *(US)*	*G* *(EU)*
T90 (degC)	Mid (143.0)	High (168.5)	Low (118.5)	Low (118.5)	Mid (145.5)	High (172.2)	High (177.5)
Aromatics (vol %)	Mid (39.0)	High (45.8)	High (45.5)	Low (32.0)	Mid (39.6)	Low (24.2)	Mid (39.4)
Sulphur (ppm)	Low (8)	Low (13)	Low (13)	Low (4)	Low (9)	High (183)	Low (<10)
Detergent	N/A				PBA		
RON	High (Premium 100)					92	96.5

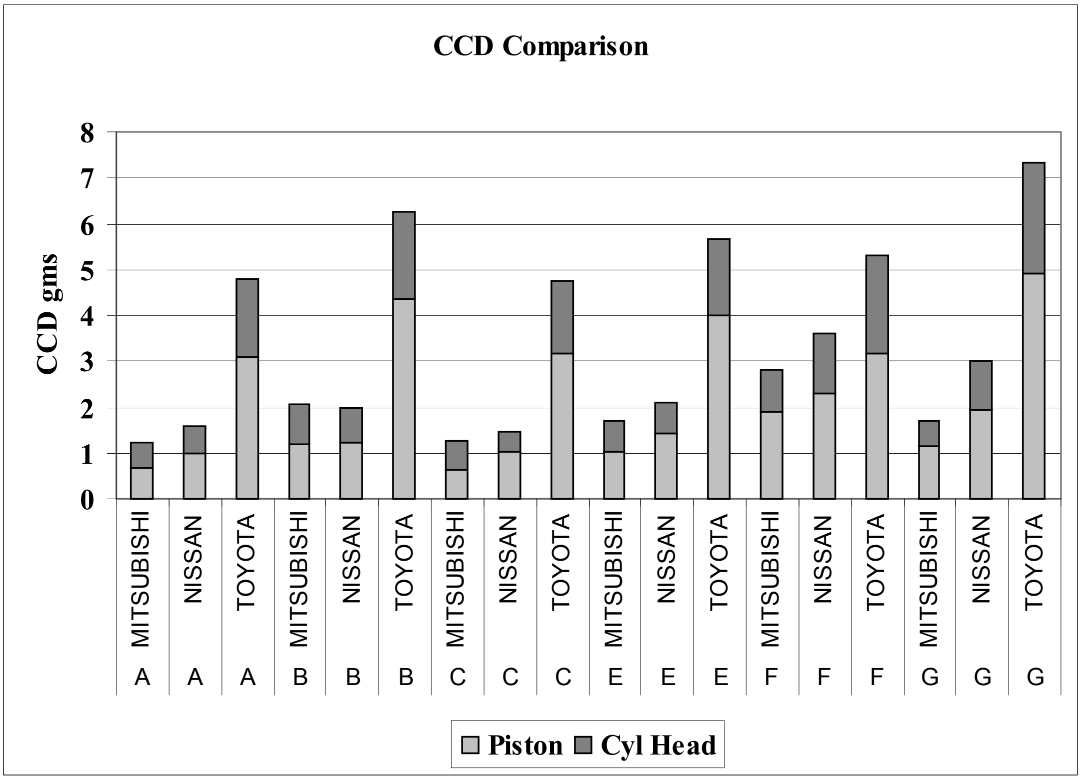
a. Phase 1

Each of the fuels was tested according to the following conditions:

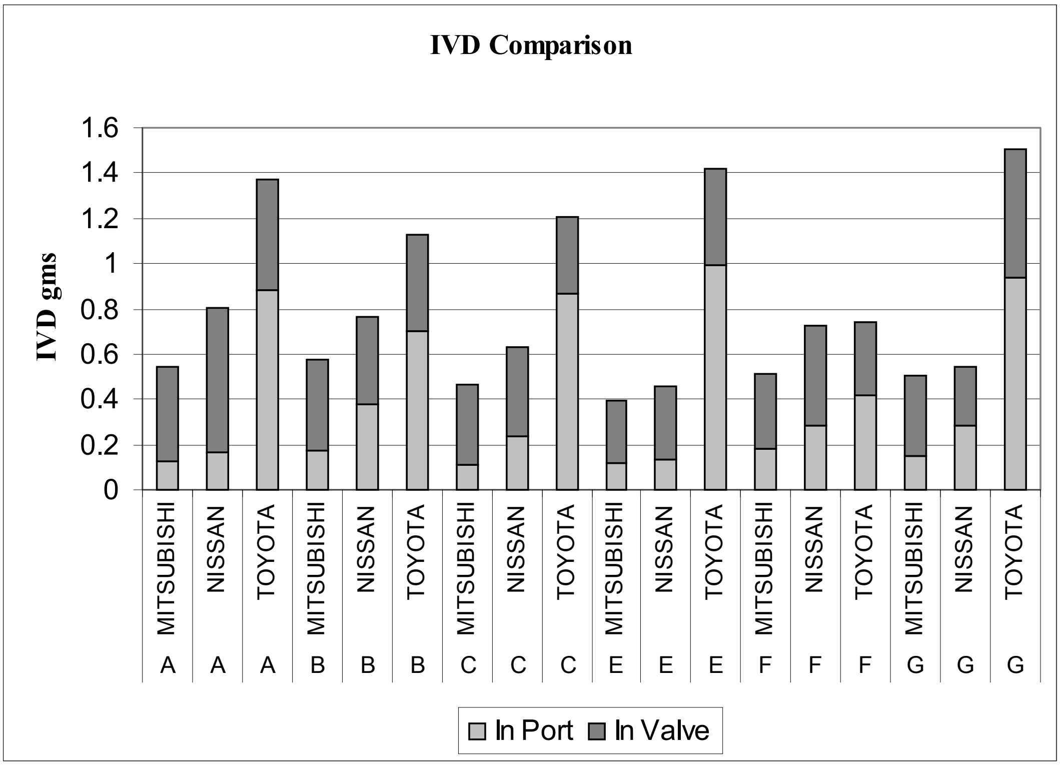
	Mitsubishi	*Nissan*	*Toyota*
Speed (rpm)	2970	3200	3606
Load (MPa)	0.72	0.63	0.80
AFR	14.4:1	14.7:1	10.6:1
Combustion	Homogenous		
Fuel Pressure (MPa)	5	11	12
EGR	with	without	without
Spark advance (BTDC)	19	22	20

The results from this work are presented below:





CCD Comparison
CCD gms
8
7
6
5
4
3
2
1
0
MITSUBISHI
NISSAN
TOYOTA
A
B
C
E
F
G
Piston
Cyl Head



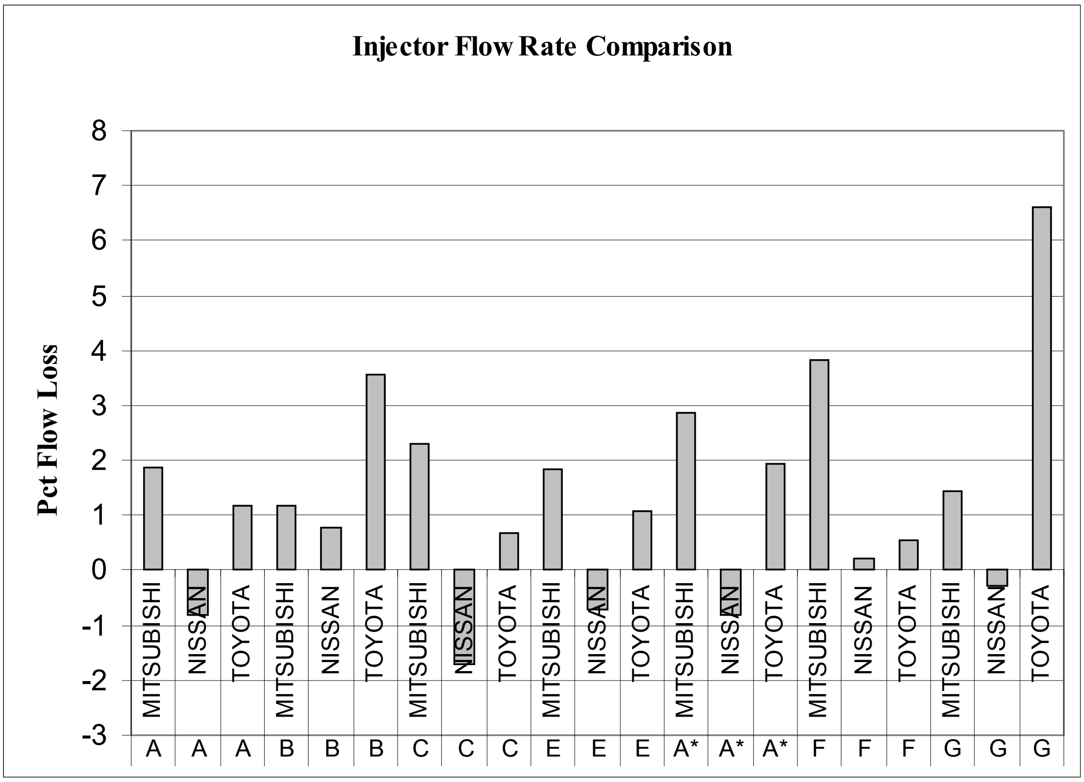
IVD Comparison
IVD gms
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
MITSUBISHI
NISSAN
TOYOTA
A
B
C
E
F
G
In Port
In Valve

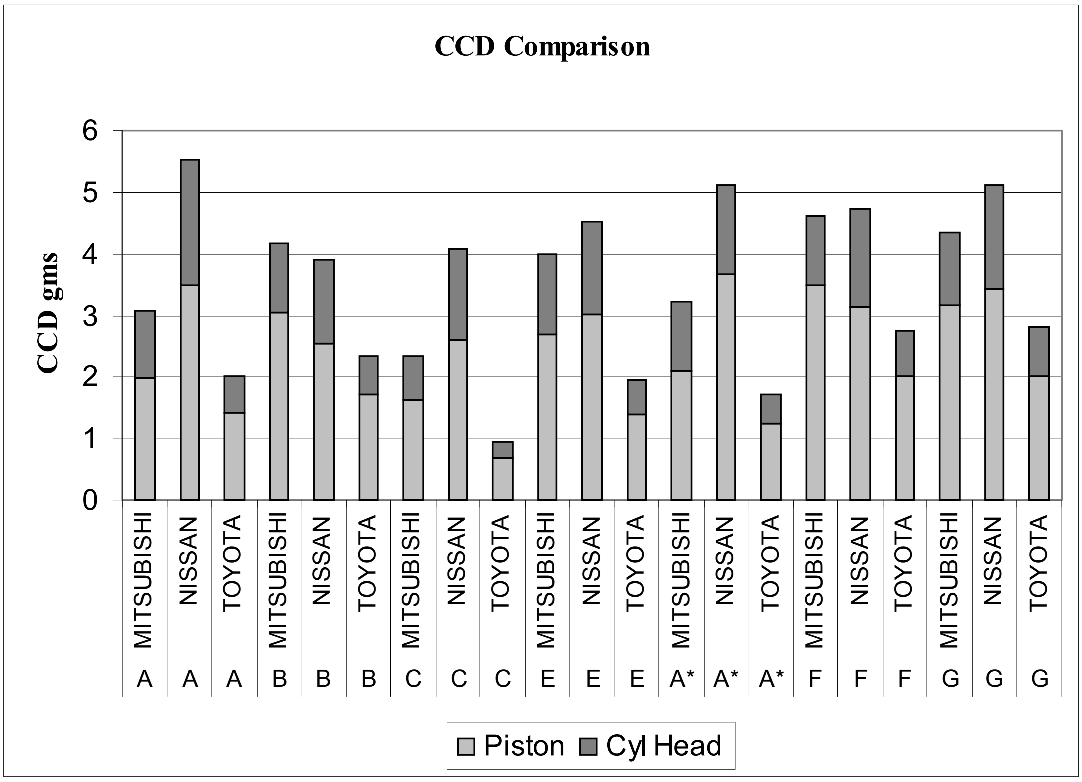
b. Phase 2

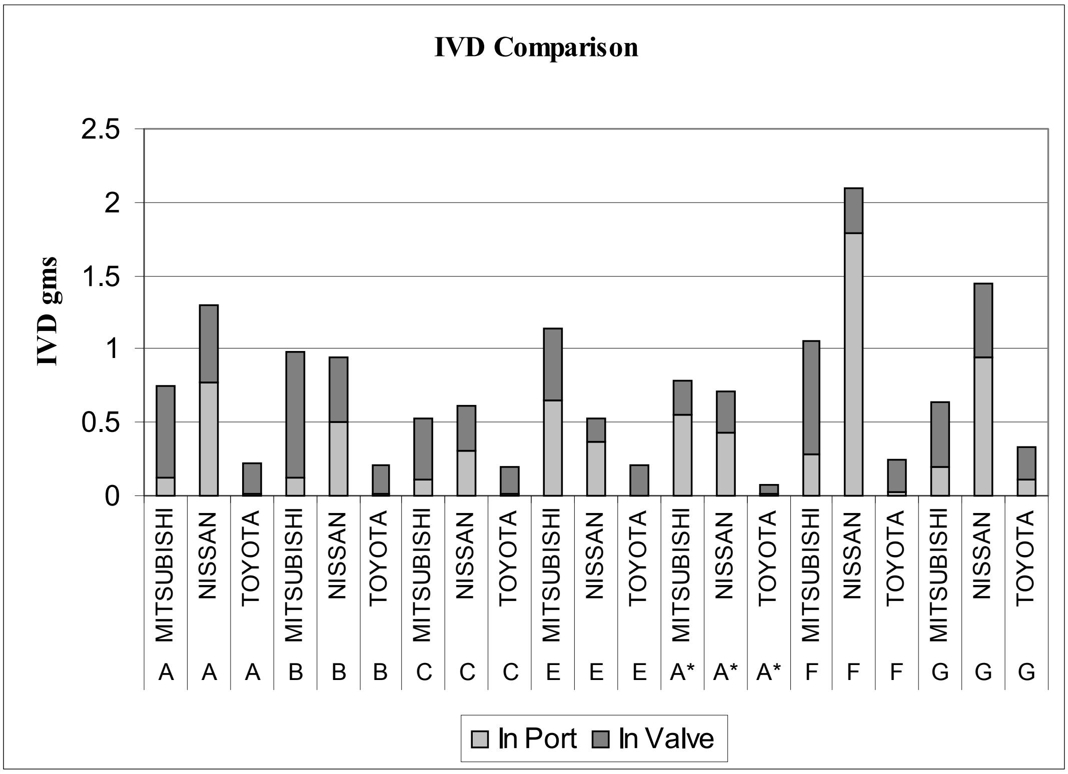
In phase 2, an additional fuel, A*, was tested. This fuel was the base fuel A with the addition of synthetic oil. The fuels were tested at the following conditions:

	Mitsubishi	***Nissan***	***Toyota***
Speed (rpm)	1550 / 1204	1600 / 1280	2004 / 1005
Load (MPa)	0.45 / 0.22	0.26 / 0.16	0.30 / 0.17
Manifold Depression (kPa)	8.3 / 19.1	14.0 / 18.0	12.5 / 16.0
AFR	32.4 / 38.8 :1	24.0 / 27.0 :1	32.8 / 35.8 :1
Combustion	Stratified		
Fuel Pressure (MPa)	5 / 5	11 / 8.5	12 / 12
EGR	with		

and the following results were obtained:







c. Engine Selection

Based on these data, the Mitsubishi engine was selected for further test development by the Task Force. Mitsubishi agreed to support the global test development with the supply of engines, parts and information and also agreed to provide continued support for the test for a period of at least five years.

5. Installation

The first meeting of the Task Force was held in July 2002 in Japan, with membership restricted to supporting companies. The following are the original 12 members:

- Afton (USA)
- Aral (Germany)
- Associated Octel (UK)
- AVL (UK)
- BASF (Germany)
- Chevron Oronite (USA)
- Kuwait (Netherlands)
- Lubrizol (USA)
- Mitsubishi (Japan)
- Prodrive (UK)
- TonenGeneral (Japan)
- Total (France)

It was agreed that the installation would be copied from that used at TonenGeneral in Japan, and all labs were requested to follow the same design. There were some inevitable differences resulting from regional safety and in-house operations. However, following a number of discussions on the impact of any variations it was agreed that the effects were likely to be minimal and could be amended, if necessary, during the test development process.

In order to exchange information quickly and cheaply between laboratories, a bulletin board was established on the Internet. With almost daily access by the majority of the Task Force members, the posting of questions and information was established as a routine method of communication, allowing the same information to be available to all.

Engines were delivered in late 2002 / early 2003, and most laboratories had them installed by end Q1 2003.

It was agreed that CEC reference oil RL 213 would be used as the test oil.

6. Comparison of Installations

Using the original OACIS test method as a base, draft 2 of the test method was issued with an agreed test procedure for comparison checks between the laboratories. The original test conditions are shown below:

Controlled Parameters

Item	Road load			WOT	Tolerance
	140 km/h	70 km/h	40 km/h		
Combustion mode	Stoichio-metric	Lean-mode	Lean-mode	Rich	
Engine speed (min^{-1})	2970	1550	1204	3750	±1%
Torque (Nm)	103.0	45.8	21.9	170	±1% ±5%(WOT)
Intake air temperature (degC)	25 – 28	25 – 28	25 – 28	25 – 28	
Coolant outlet temperature (degC)	92	92	92	92	±2
Fuel inlet temperature (degC)	26.2	25.2	25.8	24.4	
Fuel pressure (kPa)	329	329	329	329	±5%
Exhaust gas pressure (kPa)	15.2	4.6	2.2	35	±3 kPa

Recorded Parameters

Item	Road load			WOT	Tolerance
	140 km/h	70 km/h	40 km/h		
Combustion mode	Stoichio-metric	Lean-mode	Lean-mode	Rich	
Intake manifold pressure (kPa)	-20.0	-8.3	-19.1	-1.4	±1 kPa
Coolant inlet temperature (degC)					
Coolant flow rate (L/min)	64	34	27	81	
Engine oil temperature (degC)	104	83.3	78.2	110 *3	
Engine oil pressure (kPa)	507	290	221	534	
Fuel consumption (L/h)	11.0	3.0	1.5	24.7	±10%
Exhaust gas temperature (degC)	750	330	250	804	±50 degC
Blow-by gas flow (L/min)	11.1	11.3			20 max
Air-fuel ratio	14.4	32.4	38.8	12.3	±5%
Exhaust gas concentration CO (%) CO_2 (%) THC (ppm) NOx (ppm)	 0.62 14.6 1620 2200	 0.25 5.9 3920 960	 0.21 4.8 4450 340	 5.5 11.7 2130 940	
Steam partial pressure (kPa)	1.6	1.5	1.5	1.1	
Barometric pressure (kPa)	100.8	101.0	101.0	101.3	
Ignition timing (deg. BTDC)	19	23	21	13	±3 deg.
Engine oil consumption (g) (avg./max./min.)	330/390/220 (50h)	110/210/60 (Each speed×25h total)		700/750/ 680 (50h)	

In principle, it was agreed that, for the early test development stages, the same conditions would be used, but the relative time spent at each condition would be varied. For the correlation tests, these were:

140 kph	-	25 hrs
70 kph	-	12.5 hrs
40 kph	-	12.5 hrs

It was agreed that the European fuel (PC1) would form the basis of the development programme, as this had demonstrated moderate injector fouling in the preliminary tests. It was agreed that the use of a low fouling fuel may not show any significant differences and a test developed on a high fouling fuel may not produce adequate deposits when used on higher quality fuels.

The initial injector flow loss test results are shown below:

D	E	F	G	H	I	J	K	L	M	N	O
.96	1.52	1.28	1.5	3.97 *	0.46	0.8	0.37	1.8	-	-	-
		0.9				0.14					

* outlier – air intake temperature too high

This produced a mean of 0.97 and standard deviation of 0.55.

There was unanimous agreement that the severity was not adequate and steps should be taken to increase it.

7. Development Work

a. Stage 1

Following the initial round of testing, it was agreed to investigate the effect of:

- varying the air intake temperature
- extending test duration
- intermittent engine stops
- the 140 kph load stage
- cyclic operation using the same test conditions

These produced the following results:

Base 25 – 28 °C	Increased AIT 50 °C
0.37	0.53

Base 50 hrs	Extended Duration 100 hours
1.39	2.28
3.81	3.52
0.37	0.62

Base	Intermittent Stops
1.52	1.79
-	1.66

Base	Varying 140 kph
No significant difference	

Base	Cyclic Operation
No significant difference	

b. Stage 2

Information was presented to the group that changing the test conditions to those similar to the M102E IVD test procedure produced higher severity, and work was put in hand to investigate. An alternative set of test conditions was developed as shown below:

Controlled Parameters

Item	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Toler-ance
Combustion mode						
Engine speed (min^{-1})	650	1300	1850	3000	2000	±1%
Torque (Nm)	0	29.4	32.5	35	85.8	±1%
Intake air temperature (degC)	25 – 28	25 – 28	25 – 28	25 – 28	25 – 28	
Coolant outlet temperature (degC)	92	92	92	92	92	±2
Fuel inlet temperature (degC)	30	30	30	30	30	±5
Fuel pressure (kPa)	329	329	329	329	329	±5%
Exhaust gas pressure (kPa)						±3 kPa

Recorded Parameters

Item	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Toler-ance
Combustion mode						
Intake manifold pressure (kPa)						±1 kPa
Coolant inlet temperature (degC)						
Coolant flow rate (L/min)						

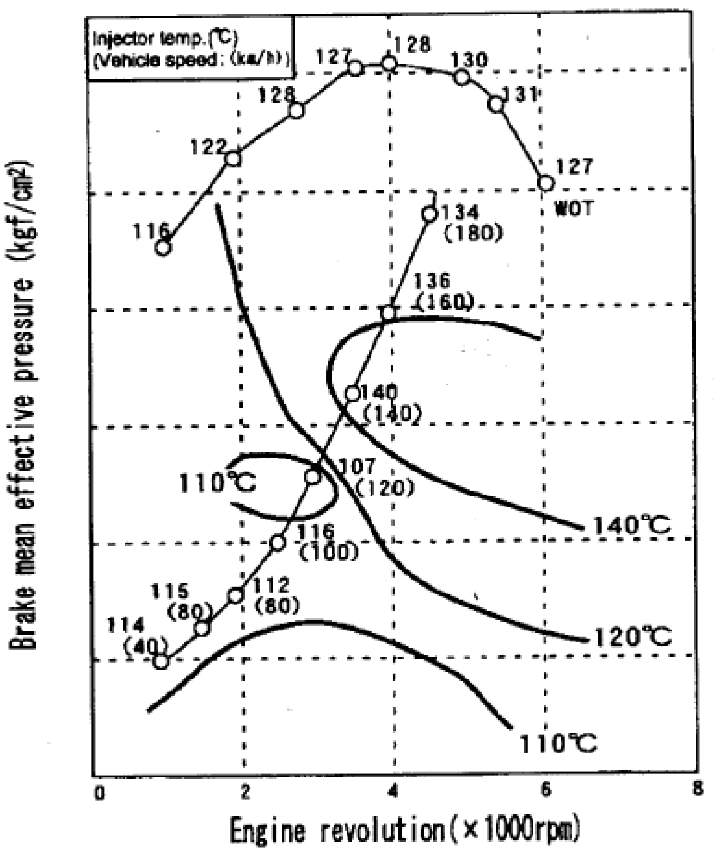
Engine oil temperature (degC)						
Engine oil pressure (kPa)						
Fuel consumption (L/h)	0.44	1.9	2.8	5.4	6.3	±10%
Exhaust gas temperature (degC)	750	330	250	804		±50 degC
Blow-by gas flow; closed PCV circuit (L/min)						15 max
Air-fuel ratio						±5%
Exhaust gas concentration CO (%) CO_2 (%) THC (ppm) NOx (ppm)						
Steam partial pressure (kPa)						
Ignition timing (deg. BTDC)						±3 deg.
Engine oil consumption (g) (avg./max./min.)						

Initial results looked encouraging, with the following reported:

Base	'M102E' variation
1.52	2.7
0.8	1.4

Data was presented to the Task Force by Mitsubishi, who had investigated injector tip temperatures.

Mitsubishi Motors 4G93 GDI Engine



As a result of this information, it was proposed to introduce a low speed / high load element into the test procedure. This was incorporated into both the original OACIS and new ‘M102E’ versions giving two revised cycles plus a third which also included a stop.

Cycle 1

Stage	Time secs	Speed rpm	Load Nm	Fuel l/hr
1	60	650	0	0.44
2	60	1300	29.4	1.9
3	120	1850	32.5	2.8
4	60	3000	35	5.4
5	120	2000	85.8	6.3

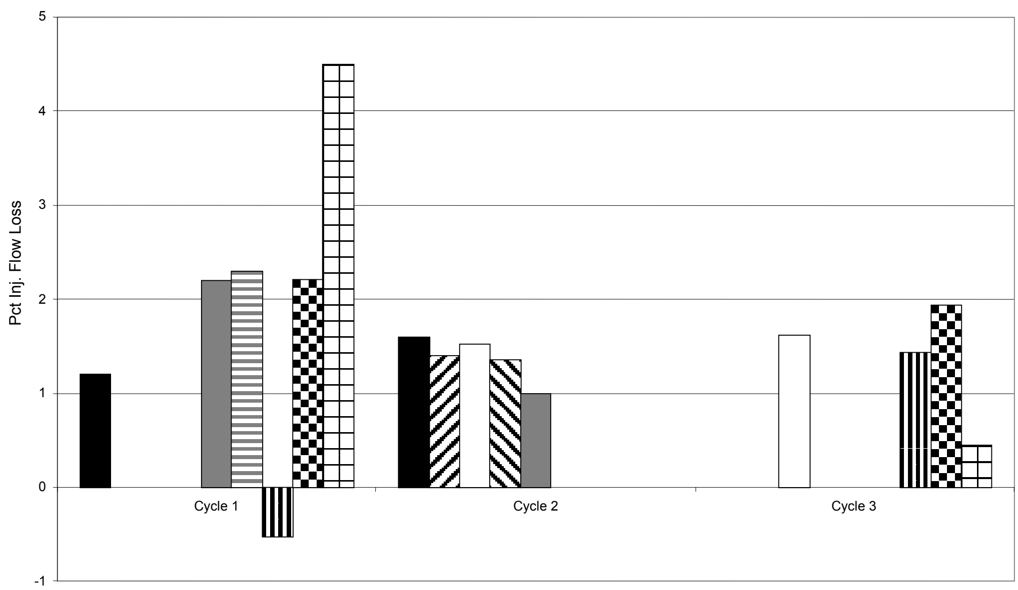
Cycle 2

Stage	Time hours	Speed rpm	Load Nm	Pe MPa	Fuel l/hr
1	5	2970	103		11
2	15	1550	45.8		3
3	15	1204	21.9		1.5
4	15	800		0.29	5.4

Cycle 3

Stage	Time secs	Speed rpm	Load Nm	Fuel l/hr
1	60	650	0	0.44
2	60	1300	29.4	1.9
3	120	1850	32.5	2.8
4	60	3000	35	5.4
5	120	2000	85.8	6.3
6	720	stop		0

The results from this work are presented below, with each lab represented by a different bar.



showing that Cycle 1 has marginally higher severity than the other two.

c. Stage 3

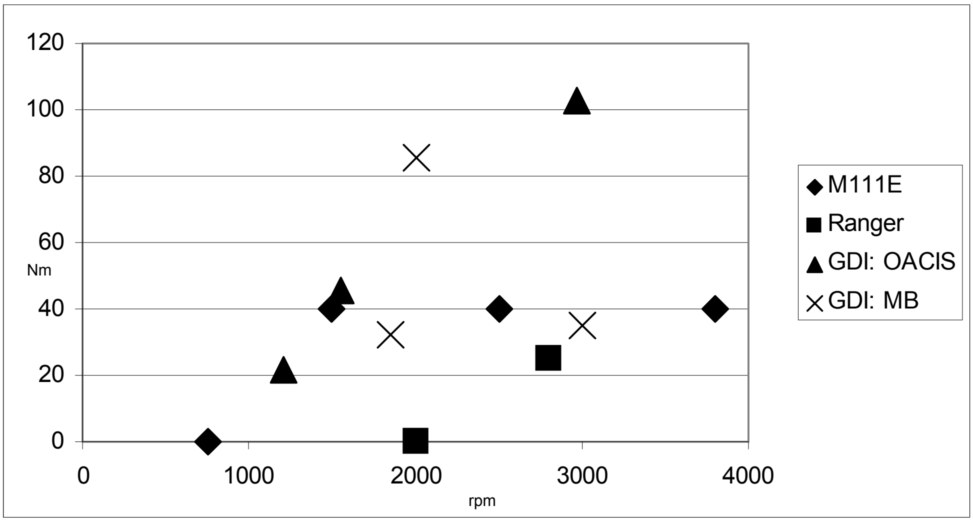
There were strong indications that little within the control of the Task Force was having any significant effect on severity. Equally there was data presented to the group showing measurable swings in severity without any obvious reason. It was decided to address the overall control of the engine, and to see if there were any parameters over which the group had no control or had not taken control.

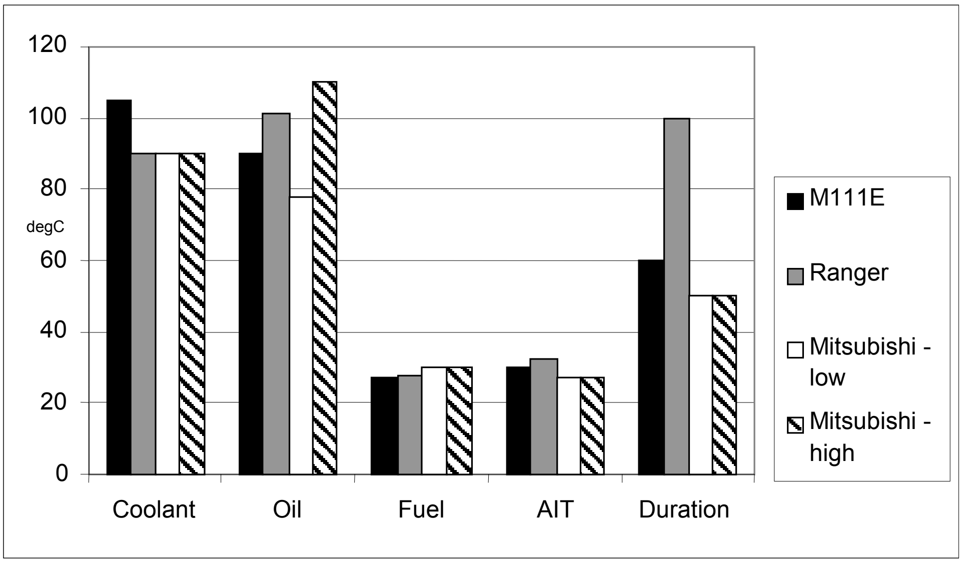
Labs conducted a range of measurements at different operating conditions. While the majority of test conditions showed agreement within a few percent, the 1850 rpm lean condition showed significant differences in inlet manifold vacuum; EGR manifold temperature; exhaust temperature; fuel consumption; b.s.f.c and engine torque. Differences were also seen at other low speed conditions. This led to concerns that all labs did not have the same ECU calibrations.

There was a proposal to switch ECU's between the test laboratories to confirm or deny the difference in calibrations, but this was not accomplished before test development was curtailed.

d. Stage 4

Comparisons were made between the Mitsubishi test conditions and those from the M111E VD and Ford Ranger tests. These are shown below:





As can be seen, there is little difference between the temperatures and durations. However, speed and load points differ markedly. Both of the Mitsubishi variants have high load points which are not present in the other tests. It was therefore agreed to incorporate a high speed medium load point into the development phase.

The change was conducted in two steps with the first being to remove the low speed conditions and the second to include a high speed condition.

The various operating conditions are shown below:

Standard Test

Item	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Tolerance
Time (sec)	60	60	120	60	120	
Combustion switch	Off	On	On	On	On	
Engine speed (min^{-1})	650	1300	1850	3000	2000	±1%
Torque (Nm)	0	29.4	32.5	35	85.8	±1%
Intake air temperature (degC)	25 – 28	25 – 28	25 – 28	25 – 28	25 – 28	
Coolant outlet temperature (degC)	92	92	92	92	92	±2
Fuel inlet temperature (degC)	30	30	30	30	30	±5
Fuel pressure (kPa)	329	329	329	329	329	±5%
Exhaust gas pressure (kPa)	-	-	4.3	5.1	5.5	±3 kPa

Revised Conditions

Item	Stage 1	Stage 2	Stage 3	Tolerance
Time (sec)	120	120	120	
Combustion switch	On	On	On	
Engine speed (min^{-1})	1204	1850	3000	±1%
Torque (Nm)	21.9	32.5	35	±1%
Intake air temperature (degC)	25 – 28	25 – 28	25 – 28	
Coolant outlet temperature (degC)	92	92	92	±2
Fuel inlet temperature (degC)	30	30	30	±5
Fuel pressure (kPa)	329	329	329	±5%
Exhaust gas pressure (kPa)	2.2	4.3	5.1	±3 kPa

Revised Conditions plus High Speed Operation

Item	Stage 1	Stage 2	Stage 3	Stage 4	Tolerance
Time (sec)	120	120	120	120	
Combustion switch	On	On	On	Off	
Engine speed (min-1)	1204	1850	3000	5000	±1%
Torque (Nm)	21.9	32.5	35	103	±1%
Intake air temperature (^oC)	25 – 28	25 – 28	25 – 28	25 – 28	
Coolant outlet temperature (^oC)	92	92	92	92	±2
Fuel inlet temperature (^oC)	30	30	30	30	±5
Fuel pressure (kPa)	329	329	329	329	±5%
Exhaust gas pressure (kPa)	2.2	4.3	5.1	??	±3 kPa

It was also agreed to investigate other issues such as:

- stoichiometric operation for complete test
- increased EGR rate
- retarded ignition timing
- increased fuel and coolant (possibly in conjunction with 100 % antifreeze) temperatures

A matrix of tests was planned as follows:

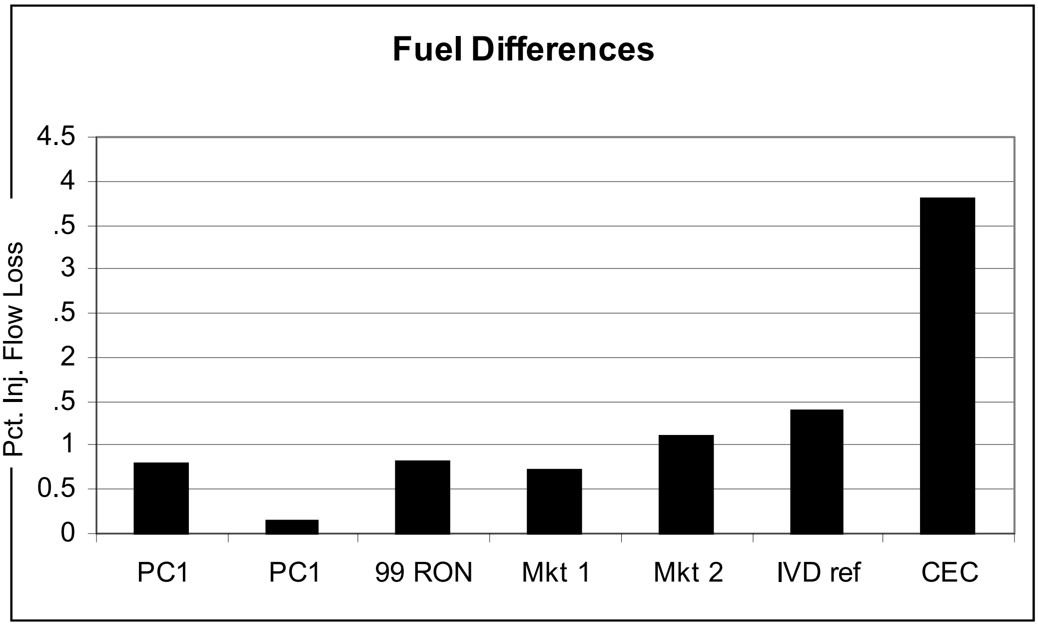
	J	J	J	K	K	K	K	K	L	L	L	M	M	M
Standard	+	-	-	+	+	+	-	best	+	+	+	+	-	-
Revised Points	-	+	-	-	-	-	+		-	-	-	-	-	-
Rev. +	-	-	+	-	-	-	-		-	-	-	-	+	+

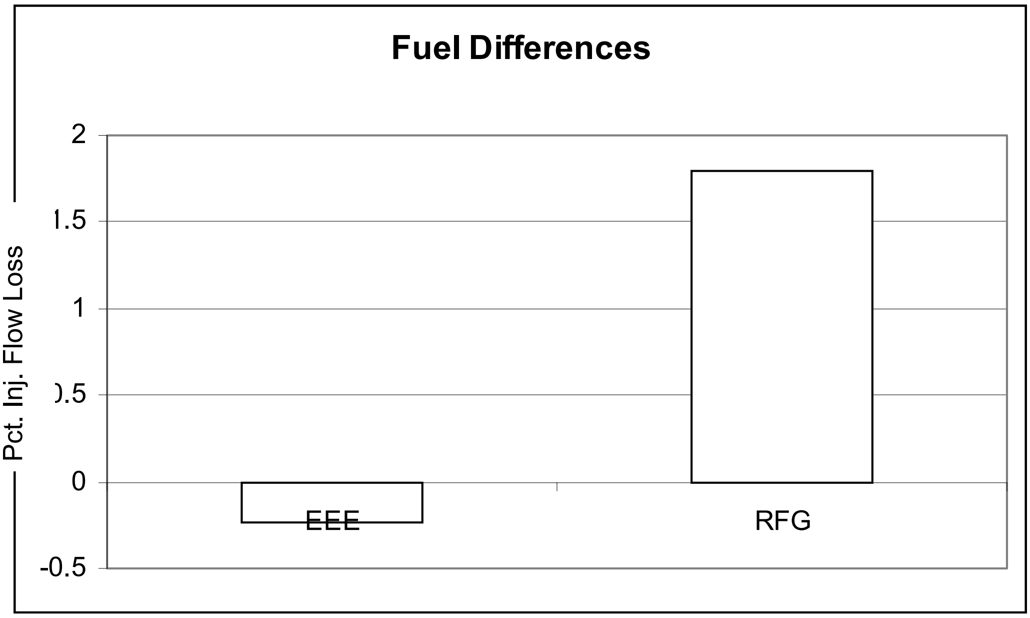
high speed														
Stoichio.	-	-	-	-	+	-	?		-	-	-	-	-	-
High EGR	-	-	-	-	-	+	?		-	-	-	-	-	-
Retard ign	-	-	-	-	-	-	-		-	+	-	-	-	-
Inc. F+L temps	-	-	-	-	-	-	-		-	-	+	-	-	+
Results	1.80	1.78	.35	1.26	1.18	1.23							3.57	

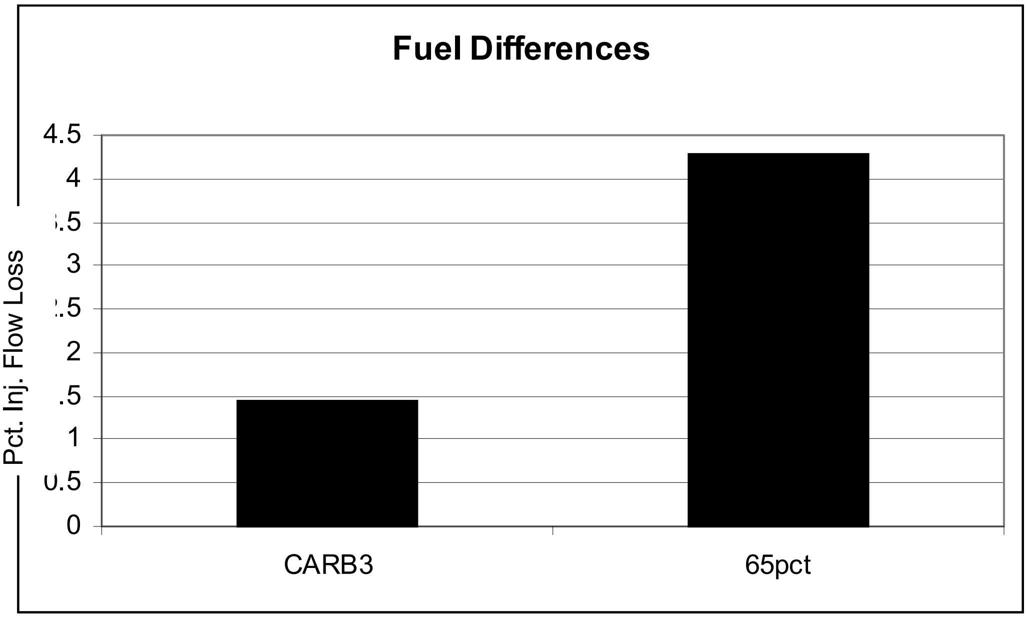
Unfortunately, the test development was curtailed before all the results were completed. However, it seems there is little difference to be gained from changing the test conditions. In fact, the only change is a retrograde one resulting from the use of the high speed test condition.

8. Fuel Effects

A number of different fuels were examined during the course of the test development process, and differences were seen in different test variants. Some of these are shown below:







Other interesting results which were unable to be followed up were injector flow losses of 9.0% and a 9.9% using a low T90 fuel on a modified OACIS test procedure.

There was insufficient data generated to demonstrate discrimination between fuel quality nor properties. Neither was the effect of additive treatments adequately examined.

Discussions were held on the capability of the test method to discriminate between fuel qualities. It was the group's belief that, at the time, the test method was not adequate. However, there were sufficient indications that the method was responsive to fuel quality to suggest that further development may provide that capability.

While increasing severity had so far eluded the Task Force, it was considered possible that improvements to precision would improve the situation.

9. Test Results

All test results from the development programmes are presented in Appendix D.

10. Rating Methods

Both the CEC and CRC rating methods were considered for use in evaluating IVD and CCD, and it was agreed that both would be used for the initial work till a decision could be made. IVD and CCD measurements were, in the event, only recorded during the initial phases of the work and it was decided to drop them till injector fouling had been defined.

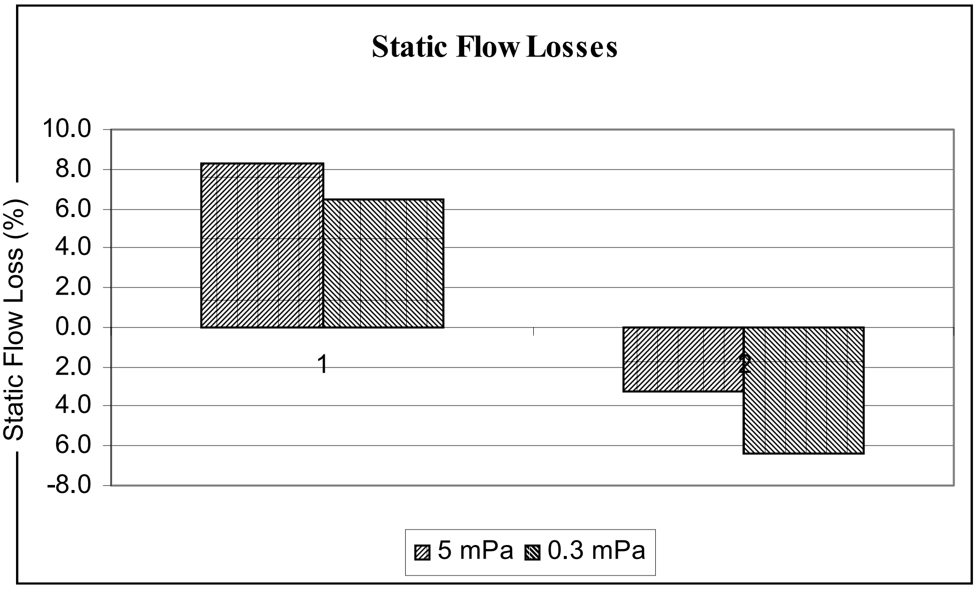
There was significant discussion on the method to be used for evaluating injector fouling with a number of options considered. There were proposals either to measure only flow loss through the injectors or to combine this with a measurement of spray characteristics. While it was agreed that, from a technology perspective, injector fouling would affect both the amount and pattern, and this would have a further effect on power, fuel economy and emissions, the quantitative measurement of spray pattern was not a defined science. It was therefore considered outside the scope of the group to develop a method which could be used within the definition of an industry test method. The price of sub-contracting of the manufacture of a usable device was considered too high, with an estimated figure of $115K (1 off) or $75K (20 off) from the USA or £25,500 from the UK (10 off).

It was left to individual labs to use in-house methods, as a supplement to the method requirements, if they wished.

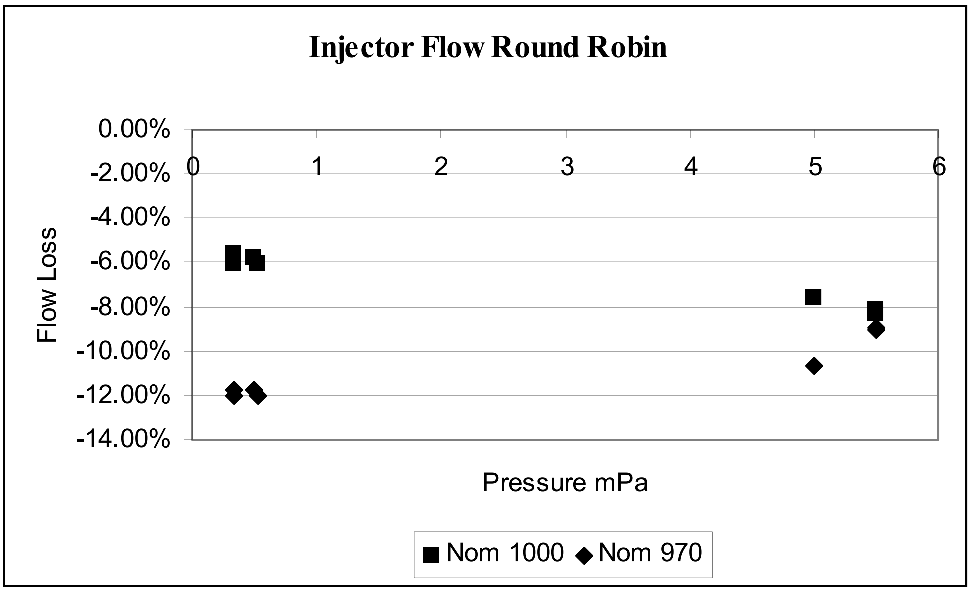
The measurement of flow loss was tackled differently in a number of labs. The following issues were considered:

- the use of fluid or air flow
- the use of pulsed or static flow
- high or low pressure

Preliminary work was conducted by Mitsubishi who compared static flow loss on three injectors rated at nominal 1000, 1090 and 970 cc / min at a pressure of 5 mPa. These were tested at the design pressure of 5 mPa and also at a pressure of 0.3 mPa, and the flow loss of the latter compared with the 1000 cc/min unit. This data is shown below, and suggests that there is a difference in flow loss measured against the base. However, if the flow loss is plotted against the design flow the results are inconclusive with limited data.



Further investigation was carried out by evaluating the same injectors at a number of the labs, each of whom had different flow measuring devices. This appears to show that the low pressure injection system provides a greater discrimination, as shown below:



11. Organisation and Procedures

The Task Force's remit to develop the first test method on a global basis was always known to be challenging. Issues which remain problems in developing new test methods on a regional basis are magnified substantially when considered on a global scale.

a. Regional Development

The three regions operate test development differently, and there was a need to coordinate testing and the associated expenses and manpower availability to accommodate each of these. In the USA, CRC member companies provided funding on a voluntary company basis under the guidance of the CRC Deposit Group of the Performance Committee. In Europe, operation followed a similar approach with individual companies providing voluntary contributions under the guidance of a CEC Special Liaison Group. However, during the test development period, this basic system changed and moved to one where a single laboratory was responsible for test development on a contracted basis, and supported by finance from interested parties. In Japan, funding was obtained from interested parties and this was used to conduct tests in a range of laboratories.

Appreciating the developing issues arising from these dissimilar systems, a meeting of the principals from the three organisations took place in October 2004. Those present reinforced the agreement made in Paris in 2000 to continue to develop test methods on a global basis. Funding issues were considered a problem but one which was not insurmountable. Each test development proposal would be assessed on a case by case basis. The existing method may be appropriate in some cases but, in others, it may be more appropriate to have development conducted by one region and adopted by the others. It was considered important, however, to ensure that each region was given the opportunity to provide input to the development process, including the objectives of the test, at an early stage.

b. Publication

There is no formal institution governing the development and publication of tests on a global basis. The current arrangement, supported by OACIS, CEC and CRC is informal and on an *ad hoc* basis. While it is relatively easy to organise publication of the method, the continuous updating is an issue that needs to be considered.

Changing the format of the procedure to meet the requirements of each regional body was considered acceptable, as was the language, providing the core technical content was maintained. There would however need to be a surveillance group established in order to provide updates as required.

Charges to be made for the method also need to be considered and, if they are levied, who should hold the copyright. Currently, CRC does not charge for test methods as these are published in research reports which are free of charge. On the other hand, CEC attempts to recover the cost of test development by charging substantial fees (> € 20,000) for new test methods. While this is not an issue for this test, it will need to be resolved for the future.

c. Quality Assurance

The QA systems of each of the organisations differ substantially. It is believed that OACIS does not have a formal QA system. CEC requires strict adherence to statistical limits for test methods to be adopted and to remain in use. The basis of this system is the need for laboratory and test stand approval according to ISO 9001 and ISO 17025, respectively. There is a requirement to provide data from tests run within a round robin exercise conducted by a surveillance group.

While the CRC does not operate a QA system, the concept of quality assurance is embedded in the USA testing scene through the ASTM committee system and the requirement to provide reference test data on a regular basis to the TMC.

An acceptable compromise, which meets the standards required by all members, needs to be sought.

d. Meetings and Communication

The conventional method of frequent meetings of participating laboratories to swap information and plan the next phases of development is costly if conducted on a global basis. The cost of flights and hotel accommodation are substantially higher for intercontinental meetings, but the lost time due to travel and ‘jet lag’ also needs to be counted.

For this group, it was agreed to organise meetings in conjunction with other meetings and conferences at which members were thought to be attending. Examples such as SAE in America, F+L Asia in Asia and CEC in Europe can be expanded upon.

The Task Force held seven meetings over a period of three years:

Date	*Venue*	*Industry Meeting*
July 2002	TonenGeneral, Tokyo, Japan	
October 2002	San Diego, USA	SAE F&L
May 2003	Yokohama, Japan	Japan SAE
December 2003	Total, Le Havre, France	
March 2004	AVL, Shanghai, China	F+L Asia
June 2004	Toulouse, France	CEC Symposium
October 2004	Tampa, USA	SAE F&L
July 2005	Prodrive, Milton Keynes, UK	*EU members only*

In addition, the Fuels Deposits Group met on seven occasions.

Date	*Venue*	*Industry Meeting*
June 2000	Paris, France (Inaugural Meeting)	CEC / SAE Symposium
October 2000	Baltimore, USA	SAE F&L
May 2001	Orlando, USA	SAE F&L
January 2002	Singapore, Singapore	F+L Asia
May 2002	Reno, USA	SAE F&L
May 2003	Yokohama, Japan	Japan SAE
October 2004	Tampa, USA	SAE F&L

The use of e-mail and conference telephone can assist in reducing the time spent at meetings. However, these did not generate the benefits envisaged. E-mails were often lost in the general melee of business communications and left unanswered. They were also prone not to have a complete circulation list, so that other members were unable to take advantage of any information generated and passed.

Conference calls were considered an appropriate means of getting all members together, but were difficult to organise when everyone was available due to the time differences. A time range of 16 hours across all regions became difficult to manage.

Japan	*Pacific USA*	*Eastern USA*	*UK*	*Europe*
07:00	14:00	17:00	22:00	23:00
16:00	11:00	14:00	07:00	08:00
00:00	07:00	10:00	15:00	16:00

To manage communications more effectively and retain information for all to access on an ‘as needed’ basis, a web bulletin board was established. This proved to be a valuable tool in communications and for the organisation of data and information.

e. Culture

In addition to the commercial differences between organisations, there are also cultural differences. These are apparent in many ways from the acceptability of other’s proposals to the ability to make commitments in meetings, but cover a range of administrative issues. There is a need to assess the impact on development strategy and be sensitive to the requirements of other cultures.

It is testimony to the individual members of the Task Force that this never became a problem.

12. Test Method

Test development was never completed. However, there were 10 drafts of the test method produced. The final draft is presented in Appendix E.

Acknowledgement

The author would like to thank all members of the CEC / CRC / OACIS Task Force and their respective companies for their considerable support during development work on this test method. In tackling the new challenge of a globally developed test method, Task Force members addressed technical, commercial and administrative issues with determination and innovation.

A. Minutes of the Inaugural Meeting, Paris 2000

SUMMARY OF THE

COORDINATING RESEARCH COUNCIL (CRC)
COORDINATING EUROPEAN COUNCIL (CEC)
JAPAN OIL & AUTO COOPERATION FOR INTERNATIONAL STANDARDS (OACIS)

ENGINE DEPOSIT WORKSHOP
IN CONJUNCTION WITH THE
2000 CEC/SAE SPRING FUELS & LUBRICANTS MEETING

PARIS, FRANCE

JUNE 23, 2000

Appendices:

Appendix A:	Agenda
Appendix B:	Attendance List
Appendix C:	N. L. Avery, "Coordinating Research Council Deposit Research Program"
Appendix D:	J. H. May, CEC "Engine Deposit Tests"
Appendix E:	M. Nakada – "Intake Valve Deposit – Test Method in Japan"
Appendix F:	Y. Akasaka, "Gasoline Bench Engine Test for Measuring CCDs"
Appendix G:	D. Peyla, "Code of Fuel/Fuel Detergent Additive Performance Testing Practices"
Appendix H:	D. Peyla, "Global Deposit Test Opportunities"
Appendix I:	Y. Takei, "Toyota's Experience on Injector Deposits in SIDI Engines"
Appendix J:	Description of the Coordinating Research Council

The Coordinating Research Council (CRC), Coordinating European Council (CEC), and Japan Oil & Auto Cooperation for International Standards (OACIS) organized an engine deposit workshop in conjunction with the 2000 CEC/SAE Fuels & Lubricants meeting. The purpose of the meeting was to identify industry needs and opportunities for establishing current and/or developing internationally agreed performance tests for the evaluation of deposits in engines. Topics for discussion included combustion chamber (CCD), valve, and fuel injector deposit effect on engine performance and emissions. The agenda for the meeting is attached and becomes Appendix A of this summary. A listing of meeting attendees is attached as Appendix B of this summary.

Workshop Conclusions & Recommendations

It was agreed the following were topics for global cooperation:

SIDI Engines

Injector deposits, Combustion Chamber Deposits (CCD), and Intake Valve Deposits (IVD)

PFI Engines

Intake Valve Deposits (IVD), and Combustion Chamber Deposits (CCD)

It was agreed the CRC, CEC, and OACIS would work toward development of worldwide-accepted test methods for both SIDI and PFI engines.

Agreed Upon Targets

SIDI

There was a desire to get an international agreement on a DI engine test procedure. An understanding of the parameters involved in formation of CCD in DI engines was needed so that we can properly choose an engine. The recommendation was to choose an engine and begin cycle development. OACIS indicated that JAMA would select an engine model and would provide and support an engine to begin test development. It was noted that all the OEM's were indicating that based on their in-house data that there was a problem with CCD formation and that we should move ahead with development of a test.

Drivers

The following agreed to lead the development of worldwide-accepted test methods for OACIS, CEC and CRC respectively:

Masahiko Nakada (Toyota Motor)
Don Smith (AVL)
Dave Arters (Lubrizol)

JAMA will propose driving cycles for consideration at a meeting to be scheduled in conjunction with the fall SAE F&L meeting in Baltimore, Maryland. JAMA will provide cycles for review to the CRC, CEC, and OACIS three weeks prior to the meeting. The cycles will be discussed at the meeting. Program details will begin to be defined and the next steps to be taken will be discussed and agreed upon.

PFI Engines

It was agreed that we will meet again in conjunction with the SAE Baltimore F&L meeting. The goal is to develop worldwide-accepted test methods for Intake Valve (IVD) and combustion chamber (CCD) deposits in PFI engines. The next step will be to correlate and recommend selection of one or more methods from the US, Europe, Japan, and Thailand for consideration in developing a worldwide accepted test method.

Drivers

The following agreed to lead the development of worldwide accepted test methods for OACIS, CEC and CRC respectively:
Yukio Akasaka (JOMO Technical Center)
Don Smith (AVL)
Toby Avery (Exxon Mobil).
The OEMs will be informed of the recommendations from this meeting and asked for feedback regarding proposed methods.

Meeting Format

The meeting agenda, Appendix A, was developed and agreed upon by the CRC, CEC, and OACIS. Tim Belian, CRC, Frank Palmer, CEC, and Masahiko Nakada, Toyota

Motor organized the meeting. Mr. Frank Palmer opened the meeting by making general introductions and reviewing the purpose of the meeting. As a first step, each group discussed industry needs, reviewed their current and recent studies, and identified opportunities for cooperation on a worldwide basis. Mr. Toby Avery, Exxon Mobil, presented the CRC Report, John May, BMW Rover, presented the CEC presentation and Masahiko Nakada, Toyota Motor, presented the OACIS Report. In addition, Yukio Akasaka, JOMO, presented an OACIS report on their Gasoline Bench Engine Test for Measuring CCDs and Yasunori Takei, Toyota Motor, presented a report on Toyota's Experience on Injector Deposits in SIDI Engines.

Following these reports, CCD, Injector, and valve deposit issues were discussed by those in attendance. Yukio Akasaka, JOMO, and Woody Woodyard, Equilon, led the CCD discussion. Yasunori Takei, Toyota Motor, and David Arters, Lubrizol, led the Injector Deposit discussion. Masahiko Nakada, Toyota Motor, and Majid Ahmadi, Oronite, led the Intake and Exhaust Valve Deposit discussion.

Points Discussed at the Meeting:

- The CRC CCD test program is leading to a comprehensive test but the need for a test shorter than 300 hours was noted.
- Autos, Oils, and Additive companies would benefit from fewer tests – especially IVD tests. There are currently more than 10 IVD tests - fewer tests are needed.
- Ford IVD tests are not acceptable for CCD. The need for one test for CCD was noted.
- It is difficult to define a simple engine-operating pattern, which duplicates all of the fuel/engine conditions.

The need for a test with a common set-up, which might have different test conditions, was discussed and supported. Dr. Nakada presented a proposal for common test setup and test engine, where depending on varying driving conditions, Japan might have one limit, U.S. another limit, and Europe another limit. He expressed this possibility with three equations where:

A = Japan Driving Cycle

B = U.S. Driving Cycle

C = Europe Driving Cycle

Each country would have its own limit with varying weighting factors for each of the drive cycles, as follows:

Limit: $L_1 = a_1A + b_1B + c_1C$

$L_2 = a_2 A + b_2 B + c_2C$

$L_3 = a_3A + b_3B + c_3C$

- The need for fundamental studies was noted. Different engines may be quite different in their formation of combustion chamber deposits. A goal in the development of a new test procedure should be to develop a test that was not too expensive to conduct. It should combine both IVD with CCD considerations.

- Some voiced the need for "cleaner" gasoline for DI gasoline engines.

- Most likely two tests will be required for IVD/CCD: one for DI and one for PFI.

- There was a desire to get an international agreement on a DI engine test procedure. It was recognized that we needed to understand the parameters involved in formation of CCD in DI engines, so that, we could properly choose an engine. A recommendation was to choose an engine and begin cycle development. OACIS indicated that JAMA would select an engine model and would provide an engine to begin test development. It was noted that all the OEM's were indicating that based on their in-house data that there was a problem with CCD formation and that we should move ahead with development of a test.

- Some cautioned that a lot of money could be spent now developing a test which would not be representative of technology in two years. It was noted that considerable work was being carried out with DI engines by the OEMs; however, few were releasing data publicly because of proprietary considerations.

- The need for a test method where you get deposit levels similar to that in the field was stressed.

- Note was made that the gum and IVD tests were used in the worldwide fuel charter because we did not currently have an accepted CCD test.

Presentations

The following presentations were made and copies are available as noted appendices.

CRC Presentation - N.L. (Toby) Avery (Exxon Mobil)

Mr. Avery presented the Coordinating Research Council Deposit Research Program. Copies of Mr. Avery's presentation become Appendix C of these minutes. Mr. Avery described CRC's recent concurrent programs.

CRC PFI and IVD test development were discussed. General issues noted were:

1. The aging test hardware for both the PFI and IVD tests.
2. The need for increased international OEM involvement in CRC.
3. The need to develop tests for new engine technology – GDI and hybrids.
4. The multiplicity of deposit tests worldwide.
5. The need for greater worldwide communication and cooperation.

CEC Presentation – John H. May (BMW Rover)

John May presented the CEC's program. Mr. May's presentation becomes Appendix D of this summary.

Mr. May described the areas that CEC had been working in, and the established methods to date. Current CEC projects were described, and the current activities of the CEC in regard to deposits.

It was noted that OEMs have expressed concerns regarding deposit formation in DI gasoline engines. Indications were that the deposit growth was different from that of conventional port-fuel injection engines. Europeans felt that it was too early to offer an engine at this time.

In regards to the DI Diesel engine, the CEC felt that the problem had been defined (high pressures, high temperatures, small holes, and low turbulence). An engine had been offered and a first project meeting had taken place on June 28, 2000. The European Union has requested a protocol on the effect of fuel additives on emissions.

Mr. May noted that CEC had no injector fouling test. There was an industry test, but it was not a CEC test. He indicated a greater tendency toward injector fouling in United States than in Europe. He noted changing characters of the fuel and felt that in the Year 2005 the fuel might be quite different than today, given the development of GDI engines. Therefore, he felt that it was too soon to begin test development. He also felt that there was such a rapid change taking place in the technology of GDI engine development that it might be prudent to wait for more of a more stable engine.

OACIS Presentation – Masahiko Nakada (Toyota), Yukio Akasaka (JOMO)

Dr. Nakada presented the OACIS presentation, which becomes Appendix E of this summary. Dr. Akasaka presented as part of this presentation the gasoline bench engine test for measuring CCDs. Dr. Akasaka's presentation becomes Appendix F of this summary.

Dr. Akasaka described the selection of the standard engine and operating conditions, and subsequent test results. Twenty-five hours at 70 kilometers per hour plus 25 hours of 40 kilometers per hours was chosen as the JASO CCD test cycle.

Effect of Test Parameters on CCD formation follows:

- Additive dosage and CCD amount had a close relationship.
- Gasoline additives varied in their CCD forming potential.

- The addition of AC-9 aromatics slightly increased CCD level relative to the undoped fuel.
- The CCD levels decreased in this order with the following oils:

SG (10w-30) < SG (5W – 30) < SJ (10W – 30)

Further work recommended was development of a CCD test procedure using a direct gasoline injection engine.

Code of Fuel/Fuel Detergent Additive Performance Testing – Dick Peyla (Oronite)

Mr. Peyla presented the Code of Fuel/Fuel Detergent Additive Performance Testing Practices. Details of Mr. Peyla's presentation are in Appendix G. The goals of the procedure are to:

- Provide a more accurate and reliable determination of whether a fuel additive meets applicable regulations
- Provide for more effective control of vehicle emissions; hence cleaner air
- Improve communication between test sponsors and customers
- Achieve more consistent application of certification testing

Global Deposit Test Opportunities – Dick Peyla (Oronite)

Mr. Peyla presented his thoughts on the need for worldwide accepted test methods, resulting in a fewer number of CCD and IVD tests. He also outlined the need for these tests (Appendix H).

Toyota's Experience on Injector Deposits in SIDI Engines - Mr. Yasunori Takei (Toyota)

Mr. Takei presented problems encountered during the development of Toyota D4 SIDI engines. Mr. Takei's presentation is attached as Appendix I and I-1 of this summary. Rough idling and poor performance were encountered. They attributed this performance to

- Build up of injector deposits
- Reduction of fuel flow rate
- Unsuitable air fuel mixture formation

- Unstable combustion and misfire

Engine specification and photographs of nozzle top before and after accumulation of deposits was shown and included in the attached presentation. From Toyota's experience, they have found that the injector tip temperature and T-90 of the testing gasoline are very important for evaluating injector deposits in SIDI engines. These two items should be considered as developing test methods for SIDI engine injector deposits. He noted, however, that the effects of other fuel properties are not clear, and it is important to make clear fuel effects before developing the test method.

Thailand's In-house IVD Test Method Development – Nirod Akarapanjarit (Petroleum Authority of Thailand)

They have been working closely with the Japanese Government utilizing Japan work but adjusting the driving cycle so it is representative of Thailand driving conditions. Mr. Akarapanjarit's presentation is not available for the summary.

Description of the CRC

A description of the CRC was distributed to all attendees and is included as appendix J.

Paris Deposit Workshop; 8/01/00

B. Membership of the Committees

Organising Committee

Dave Arters, Lubrizol, CRC
Keiichi Koseki, Tonen / OACIS
Alex Kulinowski, Afton / CRC
Toshiyuki Noda, Mitsubishi, OACIS
Paul Richards, Associated Octel / CEC
Don Smith (Chairman) FEV / CEC

World Wide Fuels Deposits Group

DON SMITH - Chairman.	FEV Motorentechnik GmbH

USA/CANADA MEMBERS

N. L. (Toby) AVERY	ExxonMobil R&E
MAJID AHMADI	Chevron Oronite
ALLEN ARADI	Afton Chemical Co.
LOREN BEARD	DaimlerChrysler
TIM BELIAN	Coordinating Research Council
FRAN BOVE	Shell Global Solutions (US)
SHIRLEY BRADICICH	Coordinating Research Council
KEVIN BRUNNER	Southwest Research Institute
ANDREW BUCZYNSKY	GM Powertrain
LEW GIBBS	Chevron Products
MITCH JACKSON	Lubrizol
JOE JOSEPH	BP
ALEX KULINOWSKI	Afton Chemical Corp.
KEN MITCHELL	Shell Canada
BILL MOST	Fuel Technology Associates
MANI NATARJARAN	Marathon Ashland
RICHARD PEYLA	Chevron Oronite
CLIVE PYBURN	PyberTech
CHUCK RICHARDSON	Ford Motor Co.
JOE RUSSO	Shell Global Solutions
MIKE SANDERS	GM
DEAN SCHOPPE	PerkinElmer Auto Research
WEI-YANG SU	Huntsman Corp.

Mail List

DON BURNETT	Chevron Phillips
SID CLARK	GM Powertrain
KEITH CORKWELL	Lubrizol
MILTON DUNLOP	Transportation Research Ctr.
ROBERT L. FUREY	General Motors Powertrain
LEE GRANT	Southwest Research Institute
CARL JEWITT	Jewitt & Associates (RFA)
ENRICO LODRIGUEZA	ConocoPhillips
MANUCH NIKANJAM	ChevronTexaco
DENNIS ROSSON	BG Products
JIM RUTHERFORD	Chevron Oronite Co.
SHIRLEY SCHWARTZ	GM Powertrain
ELLEN SHAPIRO	Alliance of Auto Mftrs.
EUGENE SILVERMAN	InTANK Services
CAROL SMITH	Ford Motor Co.
RON THARBY	Consultant
MICHAEL ZACHMEIER	BetzDearborn

CEC MEMBERS

THEO AARNINK	Kuwait Petroleum
JOHN BENNETT	Ford Motor (UK)
LYN BUNKER	CEC Secretariat
BARRY CAHILL	PSA Peugeot Citroen (France)
RINALDO CAPROTTI	Infineum (UK)
MASSIMO CARRIERO	AGIP Petroli (Italy)
RUI de BRITO	ETS (France)
GRAHAM EDEN	PetrochemCarless (UK)
LUTZ FAUBEL	APL GmbH (Germany)
JEAN-GABRIEL GRAND	TOTAL (France)
MARK HAWTHORNE	Afton Chemical (UK)
GAUTAM KALGHATGI	Shell Global Solutions (UK)
UWE LUTZ	BASF (Germany)
DEREK MACKNEY	Lubrizol Ltd., (UK)
ARD MARTENS	Texaco (Belgium)
DAVID McLEARY	BP (UK)
JOACHIM METZELTHIN	Aral (Germany)
TONO NASCH	I.S.P., Germany
JUHA PENTIKAINEN	Fortum Oil and Gas (Finland)
GARY POLKINGHORNE	Prodrive (UK)
ANDERS ROJ	Volvo Technological (Sweden)
ELNA STOMBERG	Volvo Car Corp. (Sweden)
GIORGIO TONDELLI	AGIP Petroli (Italy)
MAARTEN VAN ANDEL	Philips Analytical
KEITH WOODALL	Associated Octel (UK)

JAPAN/OTHER MEMBERS

NIROD AKARAPANJAVIT	PTT Research & Technology, (Thailand)
YUKIO AKASAKA	Japan Energy Corp.
DEBASJOS GANGULI	Bharat Petroleum – (India)
HIROHIKO HOSHI	Toyota Motor Corp.
NORIMASA IIDA	Keio University
KEI-ICHI KOSEKI	TonenGeneral Sekiyu/ExxonMobil
MASAHIKO NAKADA	Toyota Techno Service Corp.
KIYOTAKA NAKAMURA	Nissan Motor Co.
TOSHIYUKI NODA	Mitsubishi Motors Corp.
KAZUTOSHI NOMA	Mitsubishi Motors Corp.
KENICHI OKAMOTO	Nippon Mitsubishi Oil Corp.
FRANK PALMER	Consultant
JANARDAN SHARMA	Bharat Petroleum – (India)
MITSUO TAMANOUCHI	JOMO Technical Research Centre
FUMIO UEDA	Toyota Motor Corp.
KENJI YATSUNAMI	Ethyl Japan Corp.

MAJID AHMADI	Chevron Oronite (USA)
ALLEN ARADI	Afton Chemical Co. (USA)
RUI DE BRITO	ETS (France)
JEAN-GABRIEL GRAND	TotalFinaElf (France)
MARK HAWTHORNE	Afton Chemical (UK)
MITCH JACKSON	Lubrizol (USA)
KEIICHI KOSECKI	TonenGeneral Seikiyu/ExxonMobil (Japan)
ALEX KULINOWSKI	Afton Chemical Corp. (USA)
UWE LUTZ	BASF (Germany)
JOACHIM METZELTHIN	Aral (Germany)
TOSHIYUKI NODA	Mitsubishi Motors Corp. (Japan)
KAZUTOSHI NOMA	Mitsubishi Motors Corp. (Japan)
GEORGE SZAPPANOS	Lubrizol (USA)
MITSUO TAMANOUCHI	JOMO Technical Research Centre
KEITH WOODALL	Associated Octel (UK)

wwDISI Task Force

Majid Ahmadi	Chevron Oronite (USA)
Allen Aradi	Afton (USA)
Lisbeth Jansen	Kuwait (Netherlands)
Keiichi Koseki	Tonen (Japan)
Uwe Lutz	BASF (Germany)
Masayuki Miyamoto	Mitsubishi (Japan)
Ulrich Pfisterer	BP Aral (Germany)
Gary Polkinghorne	Prodrive (UK)
Don Smith (chairman)	FEV (UK)
George Szappanos	Lubrizol (USA)
Keith Woodall	Associated Octel (UK)
Jean Claude Ziberlin	Total (France)

C. Literature Search

13. Title	***Author***	***Reference***
The Effect on Vehicle Performance of Injector Deposits in a Direct Injection Gasoline Engine.	ARTERS DC, MACDUFF MJ (Lubrizol Corp.)	SAE 2000 01 2021
A Study of Fuel Additives for Direct Injection Gasoline (DIG) Injector Deposit Control.	ARADI AA, COLUCCI WJ, SCULL HM, OPENSHAWMJ (Ethyl Corp.)	SAE 1999-01-2020
Effect of Ambient Conditions on Spray Characteristics of Gasoline Injector.	LEE C, LEE K, KIM M (Hanyang Univ., Seoul, KOR)	Proceedings of 8th Symposium on Atomization VOL.8th PAGE.221-226 1999 CI
New Concept of a Direct Injection SI Gasoline Engine. Part 5. Development of a Slit Nozzle Injector.	TOMOJIRO SUGIMOTO, KEISO TAKEDA, TOMIHISA TSUCHIYA, MINORU OGAWA (Toyota Motor Corporation); SHINJI UEDA (Denso Corporation); KAZUHIRO YONESHIGE (Aisan Industry Co,.Ltd.)	JSAE Proceedings No.21-00 PAGE.9-12 2000
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Performance of Prototype High Pressure Swirl Injector Nozzles for Gasoline Direct Injection.	JANG C, CHOI S, BAE C (Korea Advanced Inst. Sci. and Technol.); KIM J, BAIK S (KEFICO Co.)	Spec Publ Soc Automot Eng No. SP1475 PAGE.1-12 1999
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An Analysis of Swirl Injector Sprays for Direct Injection Gasoline Engines.	MASK KUBO, AKIHIRO SAKAKIDA, KEN NAITO, SHIGERU KAMEGAYA, NOBUO SAKIYAMA (Nissan Motor .)	JSAE Proceedings No.68-99 PAGE.9-12 1999
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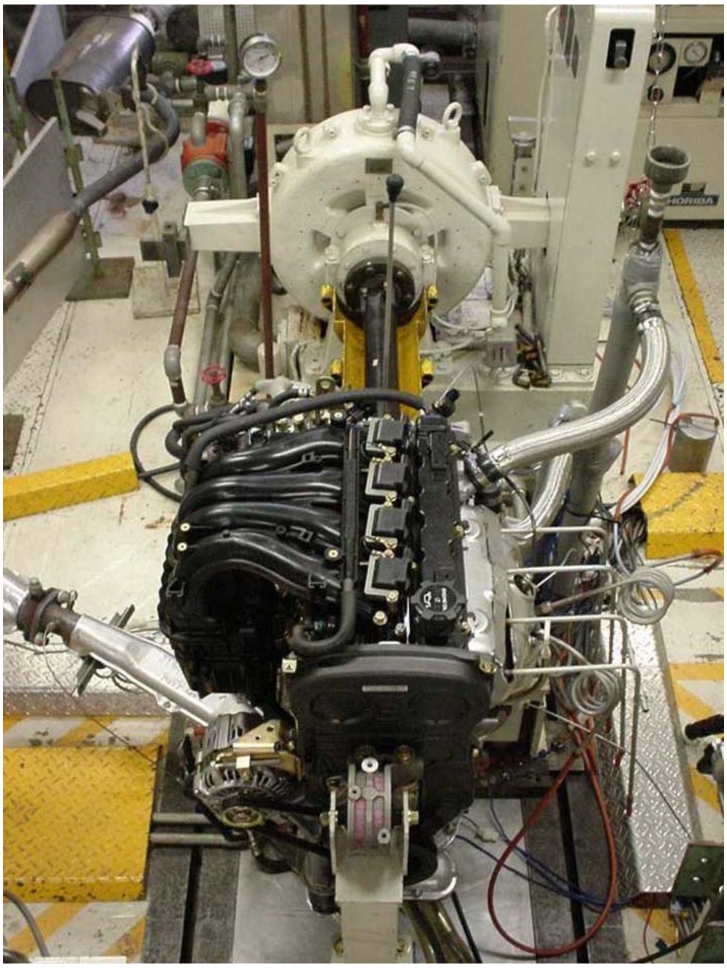
D. Test Results

	Hrs	Fuel	LABORATORIES											
Base	50	PC1	0.96	1.52	1.28	1.5		0.46	0.8	0.37	1.8			
Base	50	PC1			0.9				0.14					
Base	50	99RON							0.83					
Base	50	EEE											0.75	
Base	50	mkt 1							0.73					
Base	50	mkt2							1.11					
Base	50	IVD ref							1.39					
Base	100	IVD ref							2.28					
Base	50	CEC							3.81					
Base	100	CEC							3.52					
High AIT	50	PC1					3.97			0.53				
Extended	100	PC1								0.62				
Stops	50	PC1		1.79			1.66							
20/10 soak/run at 70 kph	150	PC1	2.2											
10/90:20	50	PC1				1.77					2.1			
10/90:40	50	PC1				1.36								
10/90:120	50	PC1				1.12								
20/80:40	50	PC1			0.9									
20/80:120	50	PC1						1.8						
20/80:20	50	PC1			0.5									
10/20/20	50	PC1							1.48					
10/20/20 x100	100	PC1							1.86					
50/0/0	50	PC1							1.62					
10/20/20:40	50	PC1							1.55					
10/20/20:120	50	PC1							1.8					
Base + LSHL	50	PC1												
Base + idle	50	PC1			1	0.59								
Base + I + LSHL	50	PC1												
Base + idle ext	100	PC1				1.2								
M102E 60 hr	60	PC2		2.7										
M102E ext	100	PC1							1.4					
M102E ext	100	99RON							0.5					
M102E ext	100	refinery							1.22					
M102E + LSHL ext Cycle 1	100	PC3			1.2	2.2	3.54		-0.53	4.5				
M102E + LSHL ext Cycle 1	100	PC3				2.3			2.21	3.2				
M102E + LSHL ext Cycle 1	100	EEE											-0.23	
M102E + LSHL ext Cycle 1	100	RFG											1.79	
M102E + LSHL ext Cycle 1	50	lowT90	1.1											
M102E + LSHL ext Cycle 1	100	lowT90				5.52								
Modified OACIS Cycle 2	50	PC3		1.52	1.6	1								
Modified OACIS Cycle 2	50	PC3		1.36	1.4								1.25	
Modified OACIS Cycle 2	50	lowT90						5.6			9.9			
Modified OACIS Cycle 2	50	lowT90									9			
Modified OACIS Cycle 2	50	CARB3											1.45	
Modified OACIS Cycle 2	50	65%ile											4.28	
Modified OACIS Cycle 2	50	lowT90	5											
M102E+LSHL+stop Cycle 3	100	PC3		1.62					1.43	0.45		1.42		
M102E+LSHL+stop Cycle 3	100	PC3							1.94					
M102E+LSHL+stop Cycle 3	100	local										3.4		
Idle	50	Jpn												8.4
Idle	50	low T90	2.3											11
Idle with intermediate inspections	50	low T90	1.9											
Idle	50	RFG											1.63	
M102E + LSHL ext Cycle 1	50	PC3								1.8			1.26	
Revised points	50	PC3								1.78				
Revised plus high speed	50	PC3								0.35		3.57		
M102E + LSHL, Stoich only	50	PC3											1.18	
M102E + LSHL + inc EGR													1.23	

OACIS

The Evaluation of Deposits in a Direct Injection Gasoline Engine



Mitsubishi 4G93

This method has been jointly developed by CEC, OACIS and CRC to ascertain the effect of fuel quality on injector, combustion chamber and inlet valve deposits in a direct injection gasoline engine. The method uses a Mitsubishi 4G93 GDI engine with a specially selected configuration, which includes the ECU.

The test method has been based on initial work carried out by OACIS on a variety of engines and fuels from around the world.

Draft 10 has been derived from Draft 9 with the following modifications:

1. Units changed from mm to cm in 1.b.4.
2. Units changed from kg.m to kg.m.sec2 in 1.b.5.
3. Typographical error ‘50/50 5’ changed to ‘50/50’ in 1.c.7.
4. Note removed from 1.e.5 as wider range oxygen sensor and A/F readout on gas analyser have been shown to be equivalent.
5. ‘FIE’ changed to ‘fuel injection’ in 1.i.1.5.
6. Clarification of MIL light illumination and solution in 1.i.3.4.
7. Indication that newer wiring harnesses are correct in 1.i.3.5.
8. Clarification of use of correction factor at wide open throttle only in 3.a.2.
9. Section 4.d removed as there is no longer any requirement to measure spray pattern. Subsequent paragraphs renumbered.
10. Paragraph 4.e.3.2 removed as no spray pattern measurement is required.
11. Paragraph 4.e.4 removed as no spray pattern measurement is required.
12. Revised operating conditions and monitored parameters for Procedure B in 3.a and 3.b.

1. Installation

a. Engine

1. The test engine is a Mitsubishi 4G93 specially manufactured for this test by Mitsubishi Motors, and it must be obtained from them.
2. The engine specification is shown in Appendix 1.
3. Details of the engine and ancillary parts are shown in Appendix 2.
4. Special tools and documentation to facilitate the engine installation and rebuilding are listed in Appendix 3, and optional parts for engine diagnostics and injector test equipment manufacture are shown in appendix 4.
5. The major engine components are identified in appendix 5.
6. The engine is mounted at four points as shown in Appendix 6.
7. Drawings of the mounting points are shown in Appendix 7, 8 and 9.

b. Dynamometer

1. This test method requires a dynamometer with a minimum power capacity of 100 kW and speed capacity of 7000 rpm. Because this test method does not include motoring tests, either a frequency control or eddy current type dynamometer can be used.
2. It is recommended that the dynamometer should provide for both a manual and automatic emergency shutdown function which activates in response to out-of-limit parameters for such items as engine coolant temperature, oil temperature, exhaust gas temperature, and engine speed.
3. The mounting dimensions for the prop shaft are shown in Appendix 10.
4. The engine centre of gravity is 19.56, 2.96, 13.24 cm from a point defined as the centre line of the crankshaft on the rear face of the cylinder block.
5. The rotational moment of inertia is 0.1789 kg.m.sec2.

c. Cooling system

1. A diagrammatic representation of the coolant circuit is shown in Appendix 11. The coolant inlet and outlet temperatures should be measured and the coolant outlet signal used to control the flow of laboratory water through the heat exchanger.
2. The system should be fitted with a pressure cap having a rating of 90 kPa.
3. A photo of the engine inlet and outlet connections is shown in Appendix 12.
4. The engine thermostat should be modified so that it is fixed in the open position, and the by-pass passage closed off.
5. A non-restrictive flow meter should be fitted to the pipe between the outlet of the engine and the inlet of the heat exchanger. The meter should be installed in accordance with the manufacturers instructions, and it is recommended that at least five diameters of straight pipe are positioned before the meter. A diagram of the typical coolant flow rates is shown in Appendix 13.
6. A Danfoss Mag 1100 sensor, which is a non-intrusive device, together with the MAG 5000 signal converter has been found suitable, and is

available in various voltages. The web site (http://www.flow.danfoss.com/), has details of contact addresses.

7. The coolant used should be a 50 / 50 5 mix of water and commercial anti-freeze.
8. The inlet and outlet of the heater matrix circuit should be connected with a flexible pipe if 15mm inside diameter and 400mm in length, containing no sharp bends.

d. Oil system

1. There is no provision for the control of oil temperature during the test. However the oil temperature in the sump should be recorded.
2. Under no circumstances should the oil sump temperature exceed 135 degC.
3. During the test CEC reference oil RL213 should be used. See Appendix 37 for specification.

e. Exhaust system

1. A diagram showing the components and dimensions of the vehicle exhaust system are shown in Appendix 14.
2. The exhaust system configuration for the test bed should maintain the vehicle format to a point at least 75 mm after the pre muffler. If this cannot be achieved due to the limitations of the test cell then the closest fit should be obtained and the configuration recorded.
3. A valve should be fitted to the exhaust outlet to enable the exhaust back pressure to be controlled.
4. Appendix 15 shows the positions of sensors for exhaust measurements.
5. If it is required to use a wide range oxygen sensor to measure AFR, this may be positioned in the pipe section between the manifold and main catalyst.

f. Air intake system

1. The components of the air intake system are shown in Appendix 16.
2. The standard vehicle system should be installed as shown. Care shall be taken to install the air duct and air intake hose in the right direction.
3. Secure the air cleaner to the engine mounting bench using an appropriate support, without causing the air intake hose to have kinks or abnormal bends.
4. The air intake temperature should be recorded at the position shown in Appendix 16.
5. The temperature of the combustion air after the EGR valve should be recorded in the position shown in Appendix 40.

g. Fuel system

1. Set up the fuel lines using proper fuel pipes and fuel hoses for fuel-injection engines as shown in Appendix 17.
2. Connect the fuel-feed line to the fuel feed inlet of high-pressure fuel pump using fuel delivery hose MR431567.
3. The delivery pressure of the low pressure fuel pump should be approximately 330 kPa at a flow of 60 – 100 L/hr.

4. Ensure that all the fuel lines are free of leakage.
5. The inner-diameters of all fuel passages should be 6mm or more.
6. Do not use copper or zinc in any part of the system.
7. A control system should be incorporated to control the fuel temperature at 30 ± 5 degC.

h. Blow-by system

1. A blow-by measurement system should be installed and arranged so that it can be connected and disconnected for the period defined in the procedure.
2. When blow-by is not being recorded the blow-by gases should be allowed to follow the normal path through the engine without interference.
3. The time period during which the blow-by measuring system is connected is defined precisely in the procedure, and it should not be allowed to remain connected at any other time.

i. Electrical system

1. An engine wiring diagram is shown as Appendix 18

1. Starting Circuit

1. Wire the starting system as shown in Appendix 19.
2. Use a starter cable with a minimum gauge of 20 mm2.
3. Install a switch either in the battery positive cable or at the negative terminal so that power supply can be cut off without having to disconnect one of the battery cables.
4. As an alternative, a motoring dynamometer can be used to start the engine, if more convenient.
5. It is known that starting problems can occur if adequate power is not supplied to the ECU and fuel injection systems during engine cranking. The minimum power for activation of the ECU is 6 volts, and it is therefore recommended to apply battery voltage directly to pins 21, 22, 23, and 24.

2. Control Circuit

1. Connect each control device to the engine wiring harness using its respective connector, as shown in Appendix 20.
2. Be sure that each connector is securely mated in the right orientation, and that excess lengths of wire are secured.
3. Route the engine wiring harness so that it is exposed to minimum radiant heat from the exhaust system, and use heat protectors where required.
4. Install the engine control unit (ECU) at a location, which is free from radiant heat and electromagnetic disturbances.

3. Additional Wiring

1. Install the following devices in order to control the engine combustion mode and to detect system failure (Appendix 18).
2. Install a switch between connector 38 and 39 in the engine wiring (hereafter called the “combustion mode select switch”).
3. Install a lamp bulb (12 V-1.4 W max.) between connector 37 and the battery positive terminal. This lamp indicates the sensor failure or wiring malfunction (Appendix 18) hereafter called the “self-diagnosis lamp”).

4. It is known that the MIL light can be illuminated as a result of not using a catalyst temperature sensor. To overcome this it is recommended that a 1000 to 2000 ohm resister is added to the circuit parallel to the oxygen sensor.
5. On some older wiring harnesses the lead to the crank and cam position sensors is too short. This can be overcome by stripping back the insulation between the two so they reach their respective sensors. Newer harnesses are of the correct length.

j. Measurements

1. The following items should be recorded

Measurement	*Location*	*Photo*
Engine speed		
Torque		
Intake manifold pressure	at the brake vacuum outlet	
Intake air temperature	at the inlet to the air cleaner	
Post EGR temperature	see Appendix	Appendix 40
Coolant outlet temperature	at thermostat housing	Appendix 21
Coolant inlet temperature	within 100 mm of elbow	Appendix 21
Engine oil pressure	at the oil pressure switch	Appendix 22
Engine oil temperature	in the oil sump	Appendix 22
Coolant flow rate	between the engine outlet and heat exchanger	
Fuel inlet temperature	between the pressure regulator and high pressure fuel pump	Appendix ###
Fuel pressure	between the pressure regulator and high pressure fuel pump	
Exhaust gas pressure	on the exhaust manifold	Appendix 15
Exhaust gas temperature	on the exhaust manifold	Appendix 15
Blow-by gas flow		
Air-Fuel ratio		
Exhaust gas concentration	on the exhaust manifold	Appendix 15
Steam partial pressure		
Barometric pressure		
Ignition timing		

2. Preparation

a. Starting Procedure

1. Engine starting procedure to initialise the ETV.

1. Connect the battery or turn on the battery switch (if equipped).
2. Place the ignition key in the “ON” position for 5 seconds (do not crank the engine).
3. Place the ignition key in the “OFF” position for 15 seconds.
4. Place the ignition key in the “ON” position for 5 seconds.
5. Start the engine.

b. Operation of combustion mode select switch

1. Idle: “Off” position
2. Off-idle below 4000 rpm: “On” position
3. Over 4000 rpm: “Off” position

Engine Speed	Switch Position		Remarks
	Off	On	
(1) Idle	Lean (W/ ISC)	Lean (W/O ISC)	The switch in “On” position will make the engine run rough.
(2) Off-idle below 4000 min^{-1}	Stoichiometric or rich combustion	Lean, Stoichiometric, or rich combustion	The switch in “Off” position will prohibit the lean combustion mode. The switch in “On” position will make the ECU automatically select the appropriate combustion mode depending on the load.
(3) Over 4000 min^{-1}	Stoichiometric or Rich combustion	Stoichiometric or Rich combustion	The switch in “On” position will cut off fuel supply at high speeds.

c. Emergency Shutdown (Recommendations)

1. The emergency shutdown function (if equipped) should be activated when any of the following conditions exist.
2. Engine speed exceeds 6500 rpm.
3. Engine coolant temperature exceeds 110 degC
4. Engine oil temperature exceeds140 degC
5. Exhaust gas temperature exceeds 930 degC

d. Check of Idle Operation

1. Engine Self-Diagnosis Check

1. Start the engine with combustion mode select switch “OFF”. After warming up, confirm that the self-diagnosis lamp is in “OFF” status. In the case “ON”, check the wirings to detect the malfunction. After fixing up the system, confirm again that the lamp is in “OFF” status.

*Note: System malfunctions can be detected and analysed by Multi Use Tester with ROM Pack or standard OBD2 compatible scanning tool (Option Parts; Appendix 4).

2. Idle Condition

1. With the combustion mode select switch in “Off” position, warm up the engine fully. Run the engine at idle and check that the following conditions are met.
2. Engine Speed: 650±50 rpm
3. CO_2 Concentration: 6.0±1%
4. Ignition Timing: 20±3 deg. BTDC
5. Intake Manifold Pressure: -50±3 kPa

3. Noise and Vibration

1. Check that the engine runs without any abnormal noise or vibration.

e. Check of Compression Pressures

1. After warming up the engine, disconnect the injector wirings to shut off fuel.
2. Measure the compression pressure of the engine and confirm that the values meet the following

Nominal value:	1720 kPa (300 min^{-1})
Lower limit:	1334 kPa (300 min^{-1})
Differences between cylinders	within 98 kPa

f. Break-in Condition

1. A new or rebuilt engine should be broken in according to the following schedule.

Operating Order	Engine Speed (min^{-1})	Shaft Power (kW)	Operating Time (min)
1	1200	0	15
2	2400	4.8	30
3	3000	9.6	30
4	3600	19.2	30

*Notes:
1. Engine oil shall be filled to the “FULL” mark on the oil dipstick.
2. Engine oil specification is not applied in this procedure.
3. The break-in operation shall be performed with the engine coolant temperature not exceeding 100 degC and the engine oil temperature not exceeding 125 degC.

g. Preparation of engine for test

1. Prior to the test, measure the flow rates of new or cleaned injectors to be tested. If cleaned injectors are used, a new injector fuel filter should be fitted.

2. Clean each intake/exhaust port and combustion chamber in the cylinder head, each piston top in the cylinder block, and each intake/exhaust valve.
3. Remove intake valves.
4. Measure each intake valve guide clearance according to the workshop manual. If the valve guide clearance exceeds the limit value 0.10 mm, replace the engine assembly.
5. After cleaning intake valve seats, insert the new intake valves to be tested and lap them.
6. After lapping, measure the intake valve weights.
7. Install new stem seals.
8. Install the injectors, intake valves, new spark plugs, and new oil filter.

h. Engine Stabilisation

1. Perform the following steps (using the engine oil and fuel that are to be tested)
2. Fill the engine with fresh RL 213 oil to the "FULL" mark on the oil dipstick (3.5 litres).
3. Warm up the engine at 2000 rpm / no load.
4. Run for a further 5-minutes after the oil temperature has reached 80 degC.
5. Increase engine speed and load to 2970 rpm 103 Nm.
6. Connect the blow-by measuring circuit and measure the blowby for no more than 5 minutes with both the PCV valve circuit open and closed.
7. The difference in the two measurements indicates the flow through the PCV valve, which should be not less than 23 L/min. A typical flow rate characteristic for the valve is shown in Appendix 39.
8. Disconnect the blow-by measuring circuit.
9. Stop the engine.
10. Wait until the oil temperature drops to 80 degC, and then drain the oil for a period of 15 minutes.
11. Fill the engine with 3 litres of fresh RL 213 oil.
12. Warm up the engine according to Section 2.h.3, 4, & 8.
13. Turn the crankshaft pulley two or three times, and position No.1 cylinder at top dead centre.
14. Wait until the oil temperature drops to 80 degC, then remove the oil filler cap (to vent the oil line), and let the oil drain for a period of 15 minutes.
15. Measure the weight of 3 litres of fresh RL 213 oil (to the nearest gram) and fill the engine with this oil.

3. Test Operation

1. Four test conditions are used to operate the test method according to the Procedure 'A', and five according to Procedure 'B'. At present the balance between each condition has not yet been confirmed. These are defined as follows:

a. Controlled parameters

Procedure 'A'

Item	Road load			WOT	Tolerance
	140 km/h	70 km/h	40 km/h		
Combustion mode	Stoichio-metric	Lean-mode	Lean-mode	Rich	
Engine speed (min^{-1})	2970	1550	1204	3750	±1%
Torque (Nm)	103.0	45.8	21.9	170	±1% ±5%(WOT)
Intake air temperature (degC)	25 – 28	25 – 28	25 – 28	25 – 28	
Coolant outlet temperature (degC)	92	92	92	92	±2
Fuel inlet temperature (degC)	30	30	30	30	±5
Fuel pressure (kPa)	329	329	329	329	±5%
Exhaust gas pressure (kPa)	15.2	4.6	2.2	35	±3 kPa

Procedure 'B'

Item	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Tolerance
Combustion mode						
Engine speed (min^{-1})	650	1300	1850	3000	2000	±1%
Torque (Nm)	0	29.4	32.5	35	85.8	±1%
Intake air temperature (degC)	25 – 28	25 – 28	25 – 28	25 – 28	25 – 28	
Coolant outlet temperature (degC)	92	92	92	92	92	±2
Fuel inlet temperature (degC)	30	30	30	30	30	±5
Fuel pressure (kPa)	329	329	329	329	329	±5%
Exhaust gas pressure (kPa)	No data	No data	No data	No data	No data	±3 kPa

2. Engine torque at wide open throttle is to be corrected using the factor shown below.

$$\text{Correction factor}=\{99/(Pa-Pw)\}^{1.2}\times\{(\theta+273)/298\}^{0.6}$$

where
Pa: Barometric pressure (kPa)
Pw: Steam partial pressure (kPa)
θ: Intake air temperature (degC)

b. Monitored Parameters

Procedure 'A'

Item	Road load			WOT	Tolerance
	140 km/h	70 km/h	40 km/h		
Combustion mode	Stoichio-metric	Lean-mode	Lean-mode	Rich	
Intake manifold pressure (kPa)	-20.0	-8.3	-19.1	-1.4	±1 kPa
Coolant inlet temperature (degC)					
Coolant flow rate (L/min)	64	34	27	81	
Engine oil temperature (degC)	104	83.3	78.2	110 *3	
Engine oil pressure (kPa)	507	290	221	534	
Fuel consumption (L/h)	11.0	3.0	1.5	24.7	±10%
Exhaust gas temperature (degC)	750	330	250	804	±50 degC
Blow-by gas flow; closed PCV circuit (L/min)	11.1	(11.3 reference)			15 max
Air-fuel ratio	14.4	32.4	38.8	12.3	±5%
Exhaust gas concentration CO (%) CO_2 (%) THC (ppm) NOx (ppm)	 0.62 14.6 1620 2200	 0.25 5.9 3920 960	 0.21 4.8 4450 340	 5.5 11.7 2130 940	
Steam partial pressure (kPa)	1.6	1.5	1.5	1.1	
Ignition timing (deg. BTDC)	19	23	21	13	±3 deg.
Engine oil consumption (g) (avg./max./min.)	330/390/220 (50h)	110/210/60 (Each speed×25h total)		700/750/680 (50h)	

Procedure 'B'

Item	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Toler-ance
Combustion mode	Lean-mode	Lean-mode	Lean-mode	Stoichio-metric	Stoichio-metric	
Intake manifold pressure (kPa)	-50.1	-12.4	-11.6	-59.4	-27.8	±1 kPa
Coolant inlet temperature (degC)	92	92	92	92	92	

Coolant flow rate (L/min)	13.8	27.9	39.9	65.0	43.2	
Engine oil temperature (degC)	No data	No data	No data	No data	No data	
Engine oil pressure (kPa)	No data	No data	No data	No data	No data	
Fuel consumption (L/h)	0.44	1.85	2.82	5.33	6.34	±10%
Exhaust gas temperature (degC)	194	256	292	657	660	±50 degC
Blow-by gas flow; closed PCV circuit (L/min)	No data	No data	No data	No data	No data	15 max
Air-fuel ratio	32.1	38.1	37.4	14.6	14.7	±5%
Exhaust gas concentration CO (%) CO_2 (%) THC (ppm) NOx (ppm)	 0.24 5.28 10542 193	 0.21 4.75 5950 495	 0.19 4.84 6471 399	 0.63 14.20 3063 1257	 0.63 14.15 3042 1609	
Steam partial pressure (kPa)	No data	No data	No data	No data	No data	
Ignition timing (deg. BTDC)	19	21	21	28	20	±3 deg.
Engine oil consumption (g) (avg./max./min.)	No data	No data	No data	No data	No data	

3. Engine oil temperatures indicate the values with auxiliary oil-cooling system in WOT condition.
4. The tolerance of fuel consumption is expanded for it is influenced by the accuracy of fuel consumption meter, atmospheric condition, fuel temperature, fuel-pulsation, and so on.

c. Engine Oil Consumption Measuring Procedure

1. After completion of the test, perform Section 2.h.9 & 10 to drain the engine oil. Measure the weight of the drained oil to the nearest gram.
2. Calculate the amount of oil consumption by subtracting the measured weight of the drained oil from the measured weight of the initially filled oil amount.

d. Recording of Operational Data

1. Operational data should be recorded in a test report similar to that shown in Appendix 38.

e. Blow-by Measurement

1. It is permissible to measure blow-by at no more than one additional point during the test, in order to confirm the acceptability of the engine for further testing.
2. The measurement should be taken at the 140 kph road load condition and the blow-by measuring circuit should not be allowed to remain open for more than 5 minutes

4. Evaluation of Results

1. Results should be recorded in a test report similar to that shown in Appendix 38.

a. Disassembly of Cylinder Head

1. After completing the engine oil consumption measurement, drain the engine coolant through the drain bolt, which located at exhaust side of cylinder block, and soak the engine for 12-24 hours.
2. Disassemble the cylinder head according to the workshop manual.
3. It is preferable to use an SP coupler (Nitto Kohki, PT1/4) or equivalent instead of the drain bolt, which prevents cylinder block damage or coolant leakage caused by the frequent coolant drainage.
4. The tightening torque of the SP coupler is 40 Nm (use the specified sealant).
5. Remove any oil from the upper side of the cylinder head using a syringe.
6. Wipe any oil or engine coolant off the cylinder head walls to prevent such oil or coolant from dripping onto the piston tops.

b. Removal of cylinder head gasket

1. After collecting and measuring the following deposits, remove the cylinder head gasket.
2. Deposits attached to the edge of cylinder head gasket.
3. Deposits attached to the gap between cylinder block and cylinder head (i.e. on the top of cylinder block and the cylinder head bottom, refer to Section 4.c.6).

c. Collection and Measurement of Deposits

1. Prior to collecting deposits, take colour photos of deposits on the piston tops, cylinder head bottoms, intake valves, intake ports, and injector nozzles as shown in Appendix 23.
2. Deposit measurement should be carried out using a vacuum collection system comprising a fine particle filter, filter holder and vacuum. A suitable device, which can be connected to a domestic vacuum cleaner, can be obtained from APL GmbH, Am Holzel 11, Industriegebeit Ost, 76829 LANDAU, Germany: phone +49-6341-9910: fax +49-6341-991199: e-mail peter.kunz@apl-landau.de .
3. Using this device deposits can be collected during the scraping process or from a container in which they have been allowed to fall.
4. When using the device, a new clean dry filter should be weighed on a precision balance with an accuracy of 1 mg, before use. Deposit weight is then calculated by reweighing and a process of subtraction.

1. Definition of Deposits

4.1. CCD

4.1.1. Deposits attached to piston top, cylinder head bottom, flame-faces of intake/exhaust valves, gasket (its edge or the gaps between cylinder block and cylinder head), and cylinder liner opposite to piston top land at its top dead centre.

4.1.2. CCD=a+b+c+d+e+f ("Others" in CCD=c+d+e+f)

4.1.3. a: Deposits on piston top (refer to Section 4.c.2)
4.1.4. b: Deposits on cylinder head bottom (refer to Section 4.c.3)
4.1.5. c: Deposits on cylinder liner opposite to piston top land at its top dead centre (hereafter simply called "on cylinder liner", refer to Section 4.c.6.)
4.1.6. d: Deposits on gasket (its edge or the gaps between cylinder block and cylinder head, hereafter simply called "on gasket", refer to Section 4.c.7)
4.1.7. e: Deposits on flame-face of intake valve (refer to Section 4.c.8.)
4.1.8. f: Deposits on flame-face of exhaust valve (refer to Section 4.c.8.).

4.2. IVD
4.2.1. Deposits attached to intake valve except its flame-face portion.

4.2.2. IVD=g

4.2.3. g: Deposits on intake valve (refer to Section 4.c.4.)

4.3. Deposit to be excluded
4.3.1. The followings must not be added to the deposits specified above.
4.3.2. i: Deposits on spark plug
4.3.3. j: Deposits on piston top land
4.3.4. k: Deposits on exhaust valve (except flame-face) or exhaust port

2. Deposits on Piston Top

1. Perform the following steps for each cylinder, starting with the No. 1 cylinder, then the No. 4 cylinder, No. 2 cylinder, and No. 3 cylinder (in that order).
2. Turn the crankshaft pulley to position the piston 20 mm before top dead centre.
3. Put gummed cloth tape over the entire surface of the top of the cylinder block, excluding the bore of cylinder head gasket, to prevent the escape of scattered deposits. Seal all holes for oil and water passage.
4. Using a knife, cut out a hole in the tape around the cylinder bore.
5. Place a protective plate on the top of the cylinder block along the periphery of the cylinder bore to prevent the escape of scattered deposits (Appendix 24).
6. Move the piston to top dead centre.
7. Scrape deposits off the piston top with a scraping tool and collect them using a vacuum collector whose filter case has been pre-weighed to the nearest 0.1 mg (Appendix 25 & 26)

8. After collecting the deposits, weigh the filter case again to the nearest 0.1 mg. Calculate the weight of the deposits from the difference in the weight of the filter case measured before and after collection of the deposits.
9. Thoroughly clean the piston top with detergent so that no deposits remain behind.

3. Deposits on Cylinder Head Bottom

1. Perform the following steps for each combustion chamber of cylinder head bottom (hereafter simply called "combustion chamber" in this paragraph).
2. Remove the spark plug and injector from the cylinder head and seal the holes for these parts with rubber plugs in order to prevent deposits from falling out of the combustion chamber.
3. Brush deposits off the edge of the combustion chamber and let them fall down into the combustion chamber.
4. Put gummed cloth tape over the entire surface of the cylinder head bottom, excluding the bore of cylinder head gasket, to prevent the escape of scattered deposits. Seal all holes for oil and water passage.
5. Using a knife, cut out a hole in the tape around the cylinder bore.
6. Place a protective plate on the underside of the cylinder head along the edge of the combustion chamber to prevent the escape of scattered deposits (Appendix 27).
7. Scrape deposits off the entire surface of the combustion chamber with a scraping tool and collect them using a vacuum collector whose filter case has been pre-weighed to the nearest 0.1 mg (Appendix 28 & 29).
8. After collecting the deposits, weigh the filter case again to the nearest 0.1 mg. Calculate the weight of the deposits from the difference in the weight of the filter case measured before and after collection of the deposits.
9. Collect the deposits on the flame-face of intake/exhaust valves (Section 4.c.8).

4. Deposits on Intake Valve

1. After collecting and measuring the deposits on cylinder head bottom and flame-faces of valves, perform the following steps for each intake valve.
2. Remove the valve from the cylinder head.
3. Submerge the valve for 10 seconds in n-heptane and shake dry.
4. Leave to dry in ambient air for a minimum of 10 minutes.
5. Weigh the valve to the nearest 0.1 mg. Calculate the weight of intake valve deposits from the difference in the weight of the valve measured before the test (new valve) and after the test.

5. Deposits on Cylinder Liner

1. Turn the crankshaft pulley to position the piston 40 mm before top dead centre.
2. Seal up the gap between piston and cylinder to prevent the escape of scattered deposits.
3. Collect and measure the deposits on cylinder liner in the same way of section 4.c.2.

6. Deposits on Cylinder Head Gasket

1. After collecting the deposits on cylinder liner, move the piston to top dead centre.
2. Scrape deposits off the area of cylinder head gasket with a scraping tool and measure them in the same way of section 4.c.3..

7. Deposits on flame-face of intake/exhaust valve.

1. After collecting the deposits on cylinder head bottom and gasket, scrape deposits on flame-face of intake/exhaust valve with a scraping tool.
2. Collect and measure the deposits in the same way of section 4.c.3.

8. Deposit on “Others”

1. Add the weights of deposits c, d, e, f specified in Section 4.c.1; 1.1, and record the total weight as the deposit on “Others”.

d. Measurement of Injector Flow Rate

1. Testing shall be conducted under the following conditions:
2. Atmospheric pressure (96 to 106 kPa)
3. Ambient temperature: 20.5 to 25.5 degC
4. Relative humidity: 40 to 60%
5. Dry solvent with the following properties should be used as the test fluid:

Properties		Specifications	
Name of Fluid		Dry Solvent	
Kinematic Viscosity	(mm^2/s)	1.20±0.01	at 23 degC
Density	(g/cm^3)	0.759±0.005	at 23 degC
Initial Distillation Point	degC	154	
10% Evaporated	degC	166	
50% Evaporated	degC	165	
90% Evaporated	degC	187	
95% Evaporated	degC	188	
97% Evaporated	degC	190	
End Point	degC	196	
Flash Point	degC	41	
Aromatic Series	(% by volume)	7.0	
Olefin Content	(% by volume)	0.5	
Insolubles	(% by volume)	92.5	

6. The test injector shall be mounted vertically on an appropriate test fixture. Details of the injector dimensions are given in Appendix 36.
7. Test fluid temperature: 23±2 degC
8. Test fluid viscosity: 1.20±0.03cst at 23 degC
9. Test fluid pressure: 5.0±0.02 MPa

1. Installation of Injector

1. The injector shall be secured to the test fixture in a manner that prevents it from being subjected to a concentrated load (so that its flow performance is not affected).
2. Connect the injector to the injector driver and test fluid circuit (refer to Fig. 32). Prior to assembling any O-ring into the interface between the injector and the test fluid circuit, check that such an O-ring is free from surface discontinuities such as nicks. Check that the face portion of the interface

on which the o-ring contacts is finished to a surface roughness of Ry 6.3 (Appendix 36).

3. Exercise care not to damage the exterior of the injector during testing to assure its proper reinstallation to the engine.

2. Preconditioning

1. Flush the injector by operating it at the specified test fluid pressure in order to remove trapped air, fluid, and vapours. Subsequent to the flushing operation, repeat the following steps until the injector is preconditioned to deliver a stable flow:
2. Operate the injector at a static flow for a maximum of 10 seconds.

3. Flow Measurement Test

1. Operate the injector according to the pulse parameters shown below.

Frequency	50 Hz
Pulse width	19.99 ms
Voltage	14.0 V

2. Using an electro balance with a resolution of 0.01 g or better (refer to Fig. 34), measure the mass flow rate for 1500 pulses (30 second period).
3. Measure the specific gravity of the test fluid.
4. Calculate the mass flow rate per unit time.
5. Using the specific gravity value of the test fluid, convert the calculated mass flow rate per unit time into the volume flow rate per unit time.
6. The standard injector flow rate is 1000 cm^3/min.
7. After completing the test, perform the following:
8. Stop the fuel pump in the test fluid circuit, let the residual pressure in the test fluid circuit escape (check this with a pressure gage), and remove the injector from the test set-up.
9. Replace the used O-rings of the injector, and reinstall the injector to the engine.

Appendix 1

Engine Specification

Item		Description	Remarks
Name of engine		Mitsubishi 4G93	GDI (Gasoline Direct Injection)
Type		Water-cooled 4 cycle gasoline	
Cylinder arrangement		In line 4 cylinders	
Combustion chamber configuration		Pent-roof cylinder head cavity plus curved piston cavity	
Valve train		DOHC 4 valves (2 intake and 2 exhaust valves) per cylinder	
Bore × stroke (mm)		81.0 × 89.0	
Displacement (cm^3)		1834	
Compression ratio		12.0	
Compression pressure / Ne (kPa/ min^{-1})		1720/300	Lower limit: 1334/300
Inlet valve timing	Opening (deg. BTDC)	15	
	Closing (deg. ABDC)	56	
Exhaust valve timing	Opening (deg. BBDC)	55	
	Closing (deg. ATDC)	15	
Valve clearance	Intake valve (mm)	(Automatically adjusted)	
	Exhaust valve (mm)	(Automatically adjusted)	
Idle operation	Speed (min^{-1})	650±50	Lean mode
	Ignition timing (deg. BTDC)	20±3	Lean mode
Engine oil capacity	At “FULL” mark on oil dipstick (litres)	3.5	Including oil in filter
Fuel		Unleaded premium gasoline	98 RON or higher
Coolant density (%)		50	By volume
Ref. 1 Accessories available in engines as shipped	Alternator	Genuine part installed	
	Thermostat	Genuine part installed	85 degC at inlet
	Air conditioning compressor	Not installed	
	Power-steering pump	Not installed	
	Intake system	Genuine parts installed	
	Exhaust system	Genuine parts or parts producing same exhaust gas pressure	
Ref. 2 Operation limits (reference values)	Fuel cut Ne	6800	ECU controls fuel cut
	Highest allowable engine coolant temperature (degC)	105	Temperature controlled by radiator
	Highest allowable engine oil temperature (degC)	135	
Ref. 3 Engine bench equipment	Exhaust system cooling system	Equipment to be used at full throttle operation	Auxiliary fans required
	Engine oil cooling system	System to be used when oil exceeds highest allowable temperature	
	Radiator	Use of genuine parts recommended	

Appendix 2

Engine Parts List

System	Parts name	Parts No.	Qty.	Remarks
Engine	Engine assembly (4G93) including Flexible flywheel Plate Plate adapter Clutch disc Clutch cover	 MD338508 MD747024 MD749712 MD771457 MD749759	1	
Equipment	Flywheel housing	ME10617	1	
	Clutch release unit	ME10100A	1	
	Under stay	ME10614	1	
	Insulator (flywheel housing)	ME10622	2	
	Front upper stand	ME10610	1	
	Left mounting bracket	MB691231	1	[EU]
	Bolt (left mounting bracket)	MU242005	3	[EU]
	Bolt (front upper stand)	MB309010	1	[USA]
	Nut (front upper stand)	MB176638	1	[EU][USA]
	Mount insulator (right or left)	MB309504	2	
	Remote control release mechanism	ME20100A	1	
	Clutch release cable	MB527399	1	
	Propeller shaft	MB154421K	1	
	Propeller shaft attaching bolt	MB154094K	4	
	Starter	MD360368	1	[EU][USA]
	Bolt (starter)	MF140268	2	[EU][USA]
	Fuel delivery hose	MR431567	1	
	Fuel pressure regulator	MD320550	1	
	Fuel filter	MB220793	2	
	Adaptor (fuel pressure regulator)		1	
Air intake system	Air cleaner assembly	MR497504	1	
	Air flow sensor	MD336481	1	[EU]
	Air intake hose	MR497521	1	
	Duct	MR497518	1	[EU][USA]
	Hose clamp (on T/B side)	MF661137	1	[EU][USA]
	Hose clamp (on AFS side)	MF661142	1	[EU][USA]
	AFS gasket	MD151672	1	[EU][USA]
Exhaust system	Front pipe	MR497630	1	
	Catalytic converter	MR597008	1	
	Centre pipe	MR497637	1	
	Main muffler	MR497652	1	
	Gasket (F/P, catalytic converter, and C/P)	MB687002	3	[EU][USA]
	Gasket (M/M)	MB687012	1	[EU][USA]
	Catalytic converter temperature sensor	MR507359	1	
Control system	Test Bed harness assembly	MN131007	1	Special part
	Test bed ECU	MN132875	1	Special part
	Injector driver	MD340897	1	[EU]
	Throttle valve controller	MR514479	1	
	Accelerator pedal position sensor	MR507419	1	
	Control relay (ETV)	MD759545	1	[EU][USA]
	Control relay (INJ driver)	MD759545	1	[EU][USA]
	Control relay (MPI)	MR312504	2	[EU][USA]

Appendix 3

Special Tools and Documentation

System	Parts Name	Parts No.	Qty.	Remarks
Special tools	End yoke holder	MB990767	1	
	Crankshaft pulley holder pin	MD998719	1	
	Camshaft oil seal installer	MD998713	1	
	Circular packing installer	MD998762	1	
	Cylinder head bolt wrench	MB991653	1	
	Adjusting bolt	MD998738	1	
	Tension pulley socket wrench	MD998767	1	
	Spark pug wrench	MB991398	1	
	Oil filter wrench	MB991396	1	
	Air bleed wire	MD998442	1	
	Valve spring compressor	MD998772	1	
	Valve stem seal installer	MD998775	1	
	Liquid gasket	MD970389	1	
Service Documents	Workshop manual	PWME0021	1	
	Engine workshop manual	PWEE9502S	1	
	Engine workshop manual	PWEE9013S	1	
	Engine workshop manual	PWEE9025S	1	

Appendix 4

Optional Parts

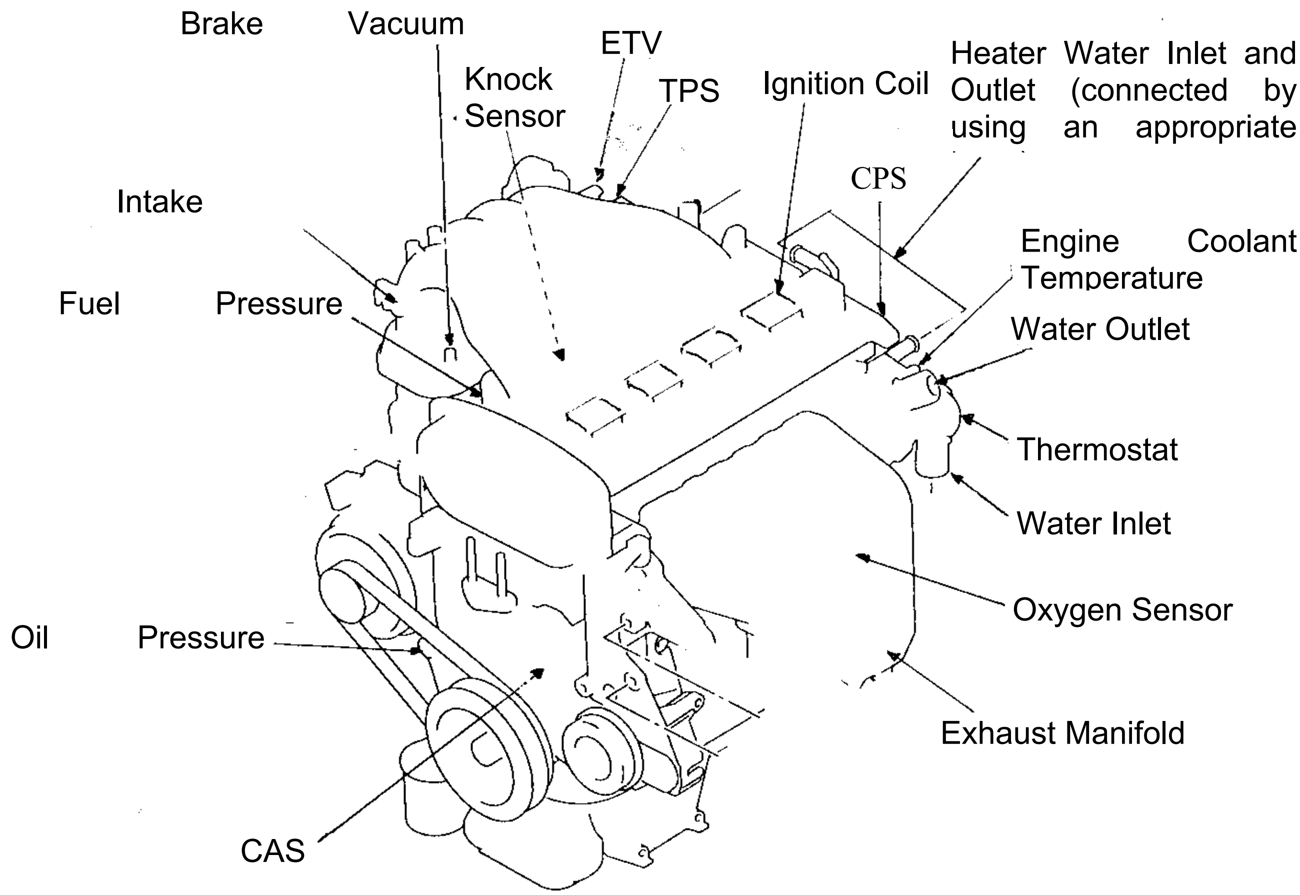
System	Parts Name	Parts No.	Qty.	Remarks
Diagnosis	Multi use tester	MB991502A	1	Use: Engine diagnosis: Engine data monitoring
	ROM pack	MRP	1	
	alternative - Snap-On MT2500 or equivalent			
For injector test rig	Injector driver connector	MN180739	1	With the 200mm conductor
	Injector connector	MN180740	1	With the 200mm conductor

*Note: The following parts are used in different positions on bench (refer to Section 2.1).

Left mounting bracket:	Engine front
Front roll stopper:	Engine exhaust side
Rear roll stopper:	Engine intake side

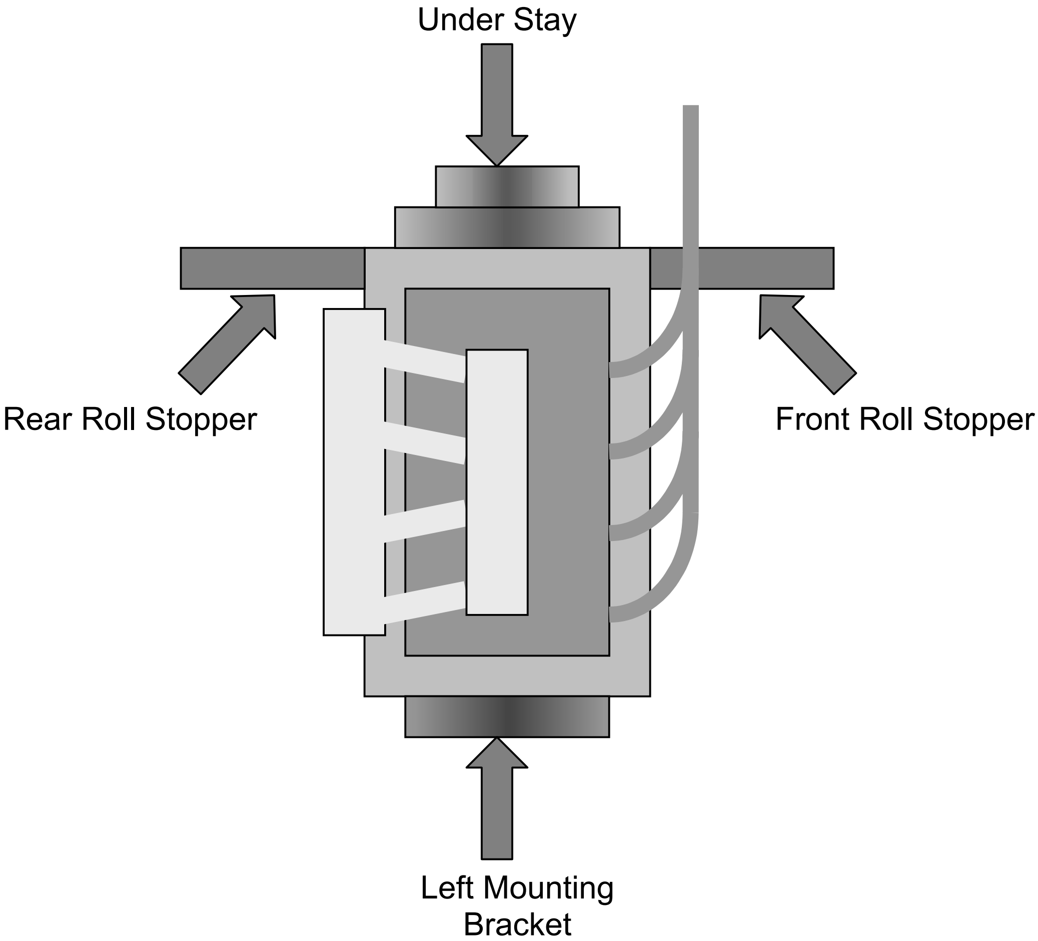
Appendix 5

Major engine components



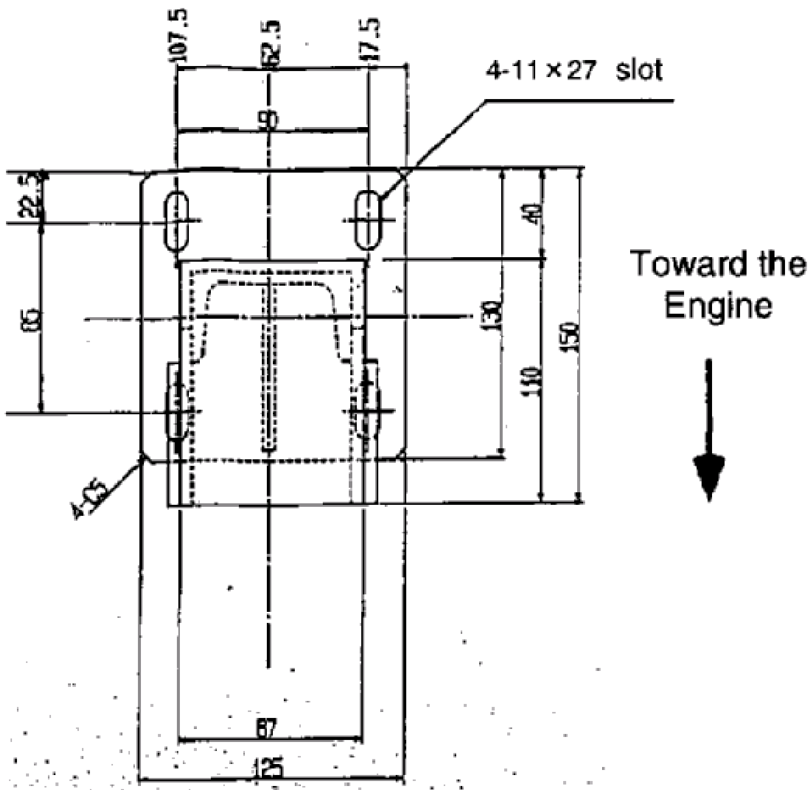
Appendix 6

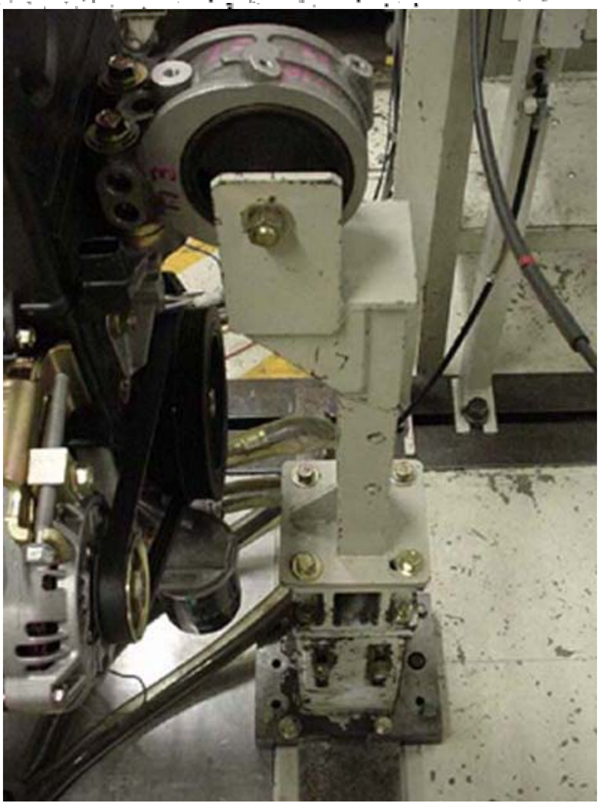
Engine Mounting Points



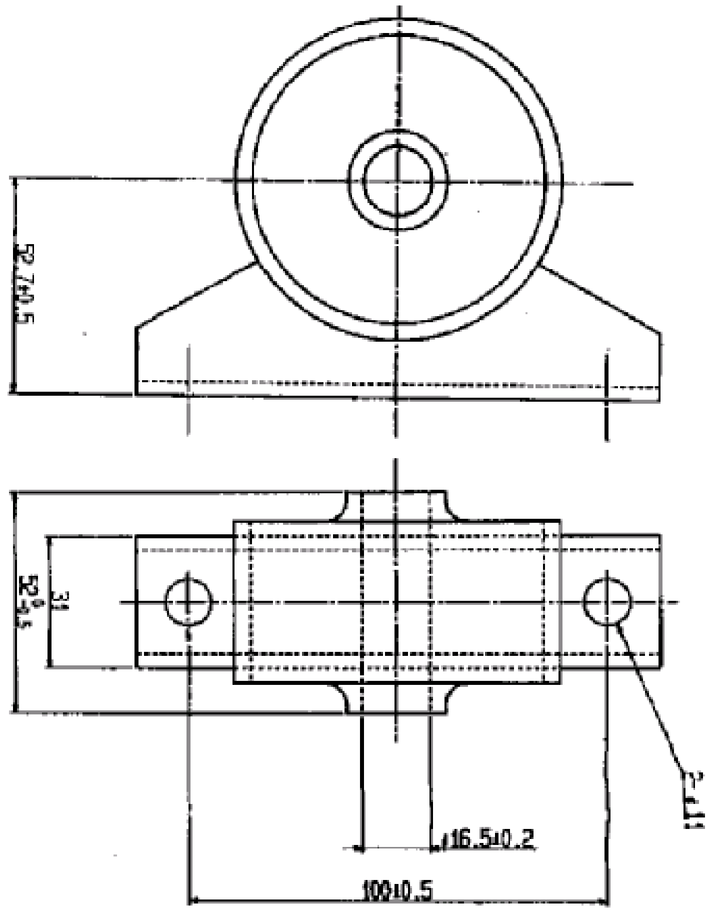
Appendix 7

Front Upper Stand Dimensions





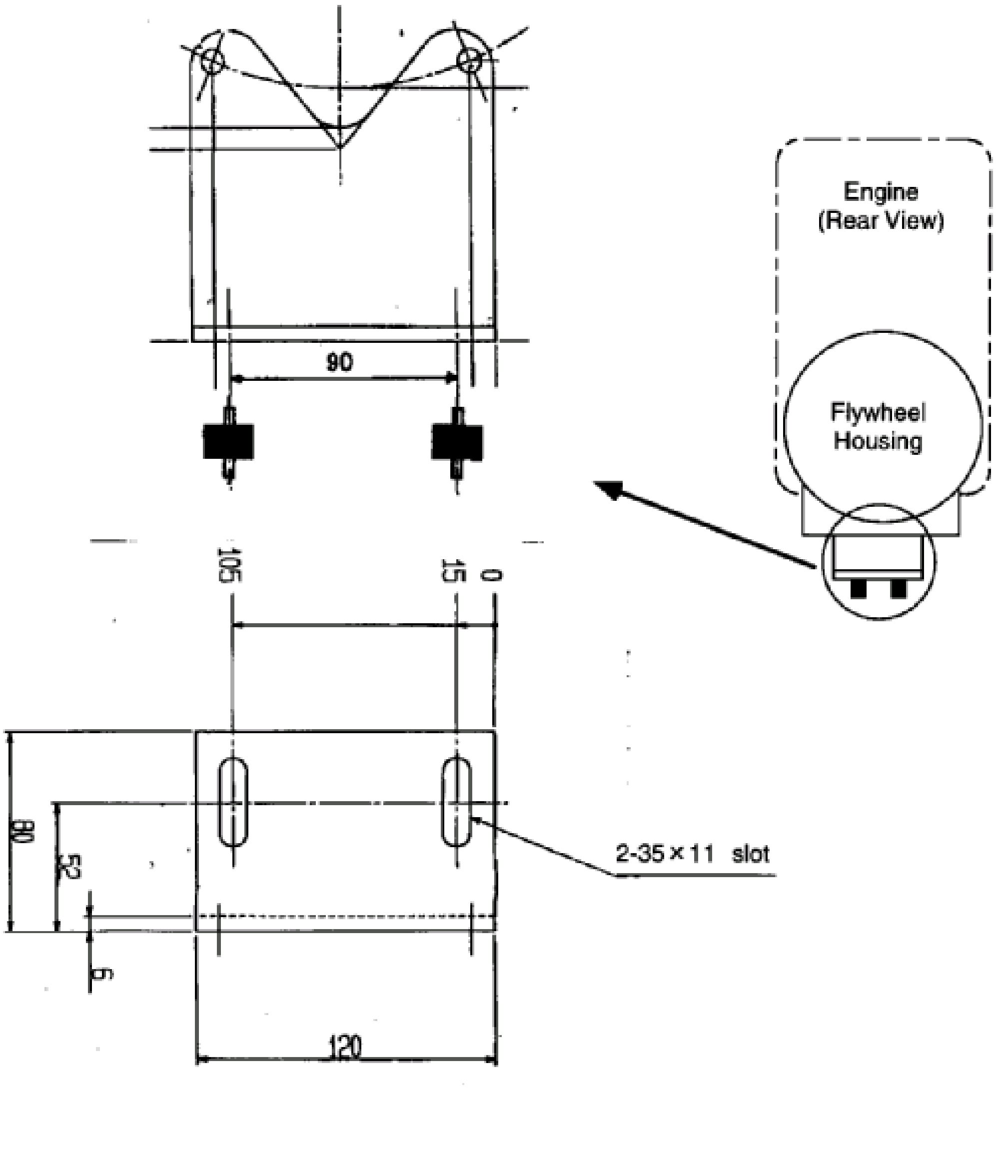
Appendix 8



Front and Rear Roll Stopper Dimensions

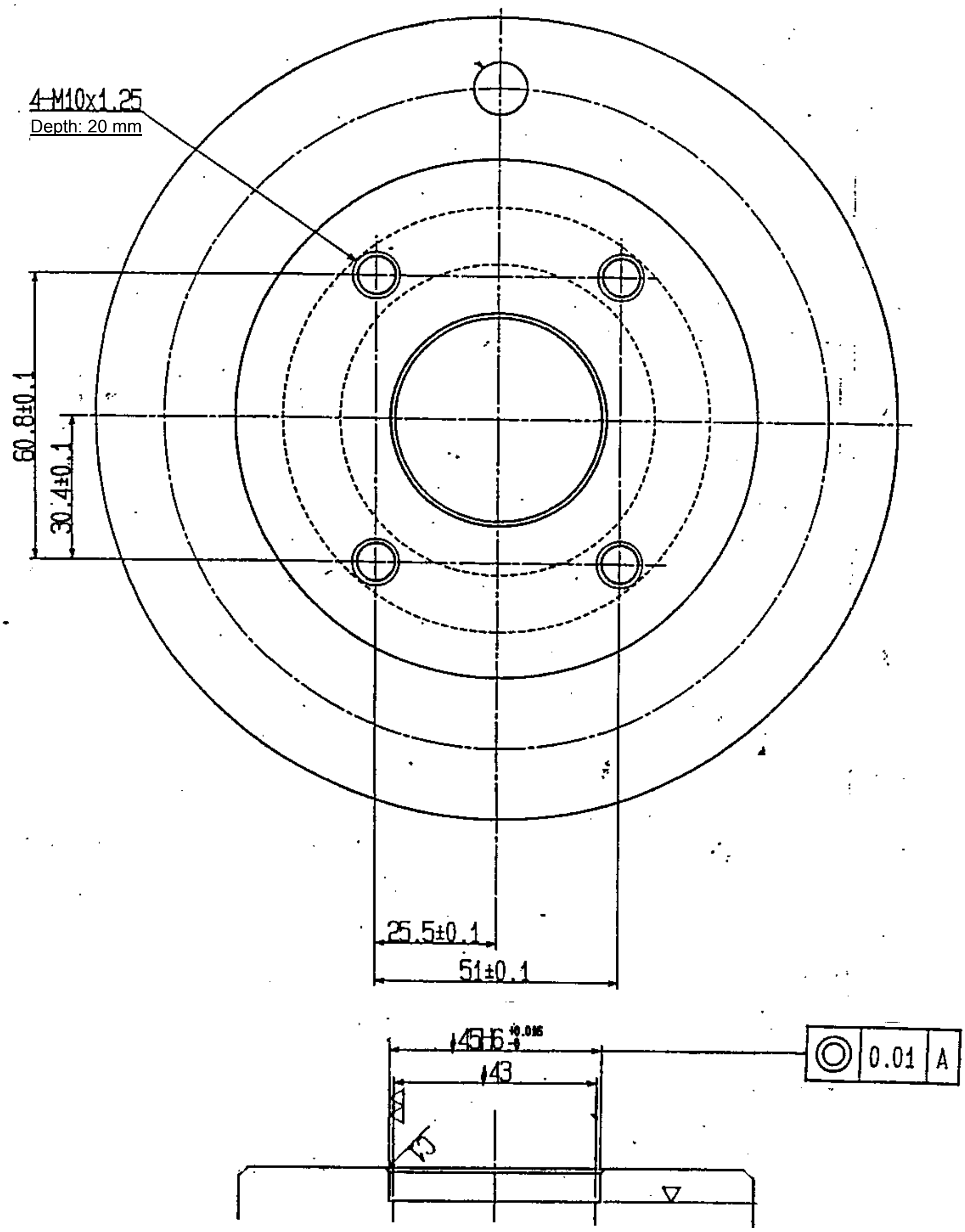
Appendix 9

Flywheel Housing Mounting Dimensions



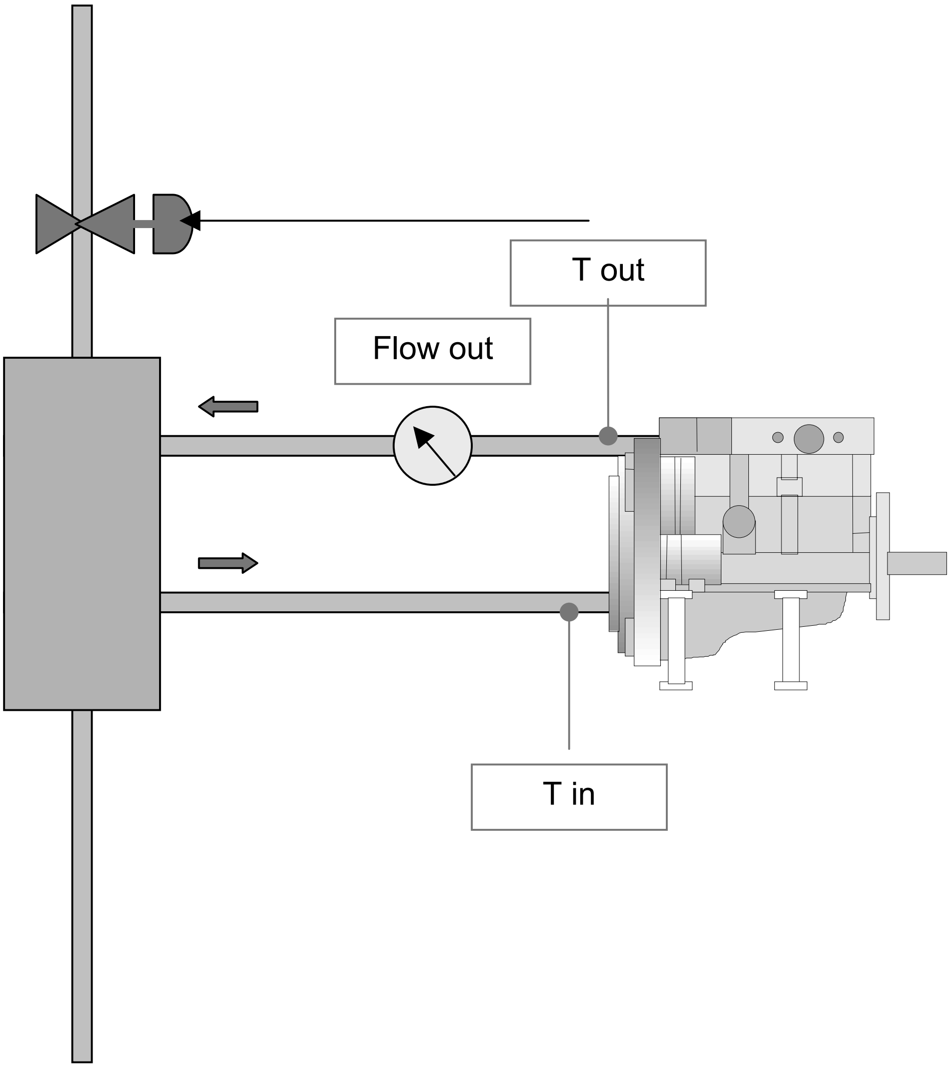
Appendix 10

Prop Shaft Mounting Dimensions



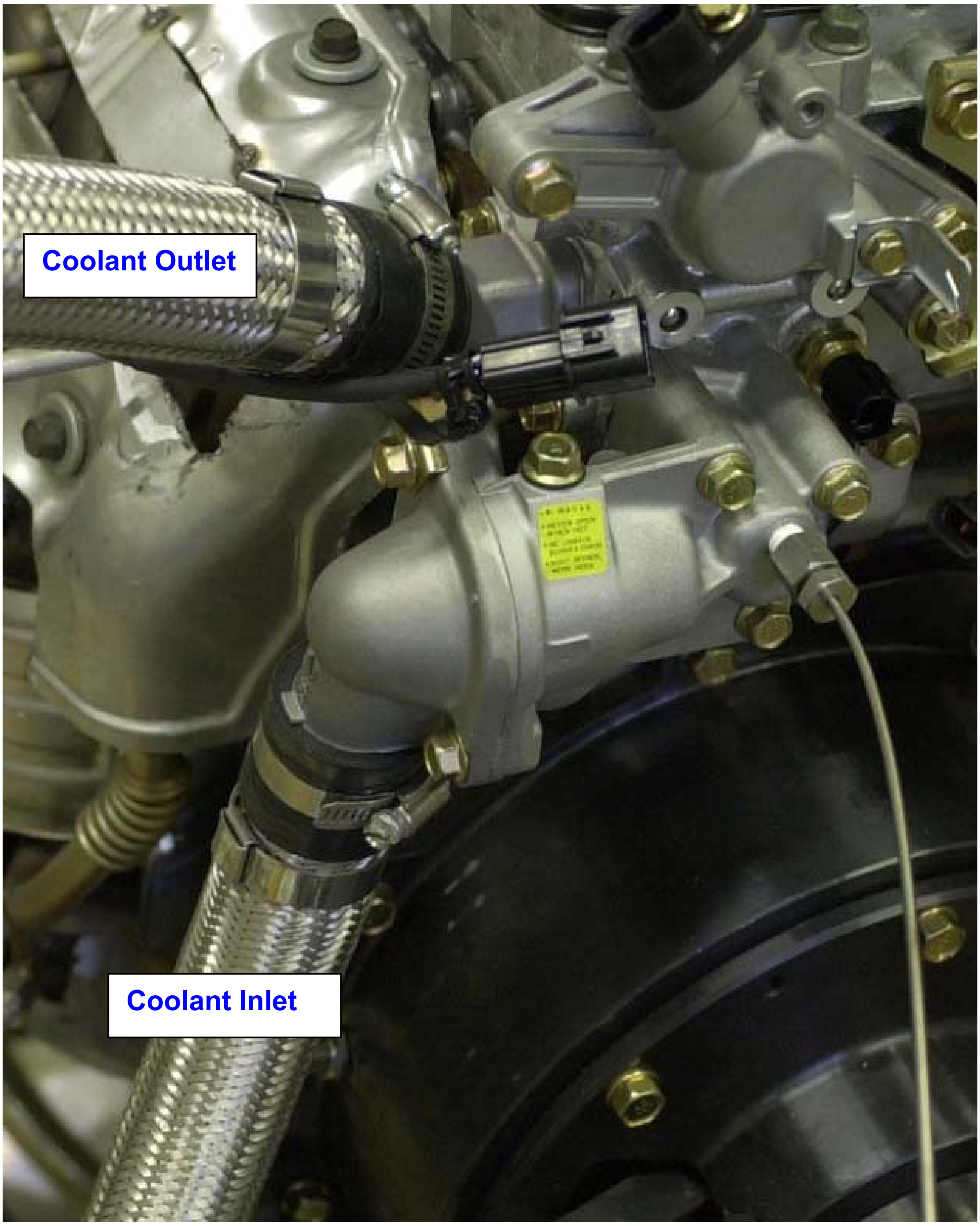
Appendix 11

Coolant Circuit



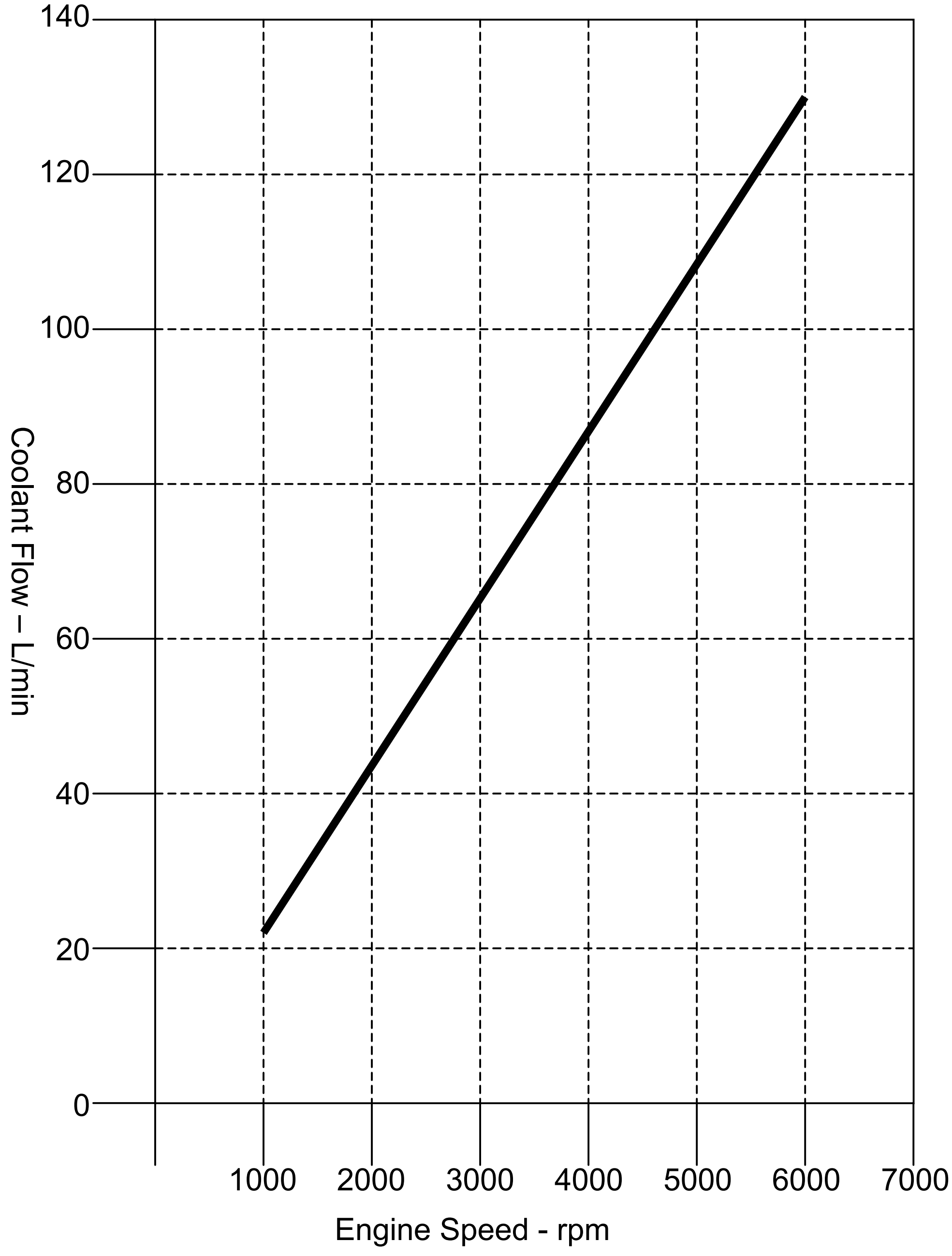
Appendix 12

Photo of Coolant inlet and outlet positions

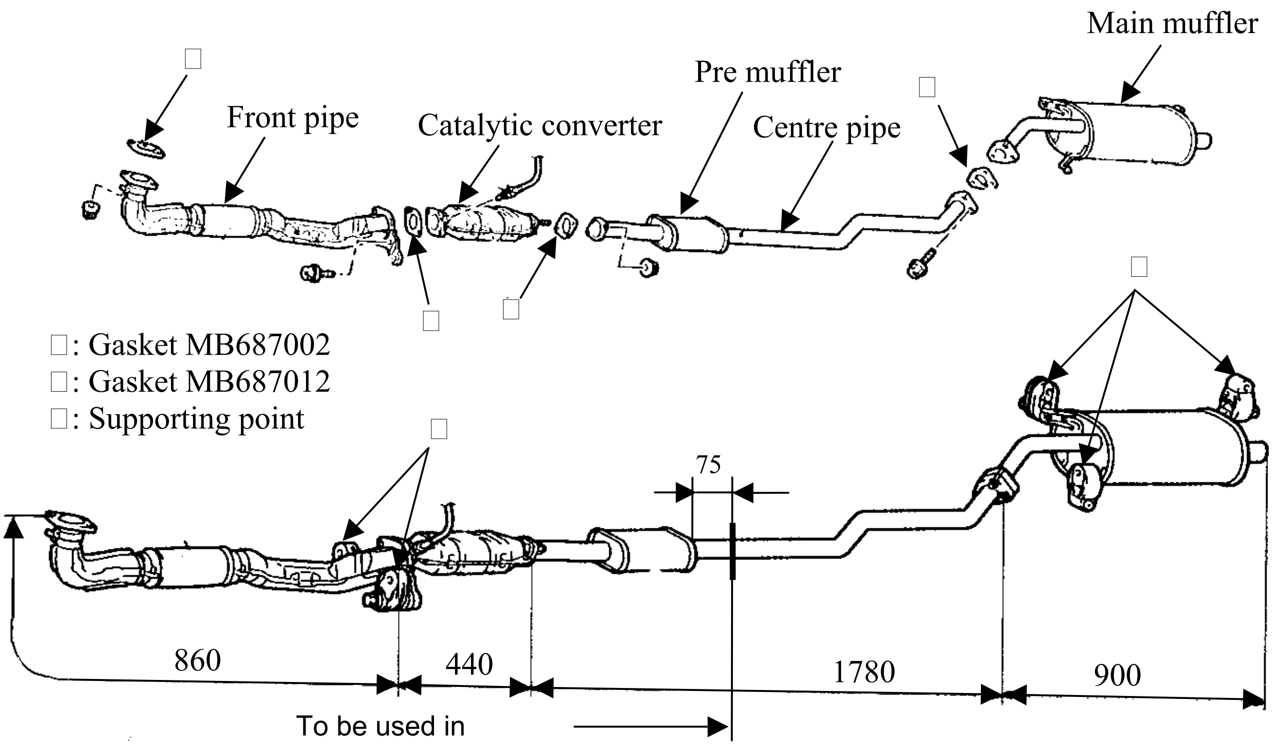


Appendix 13

Typical Coolant Flow Rates

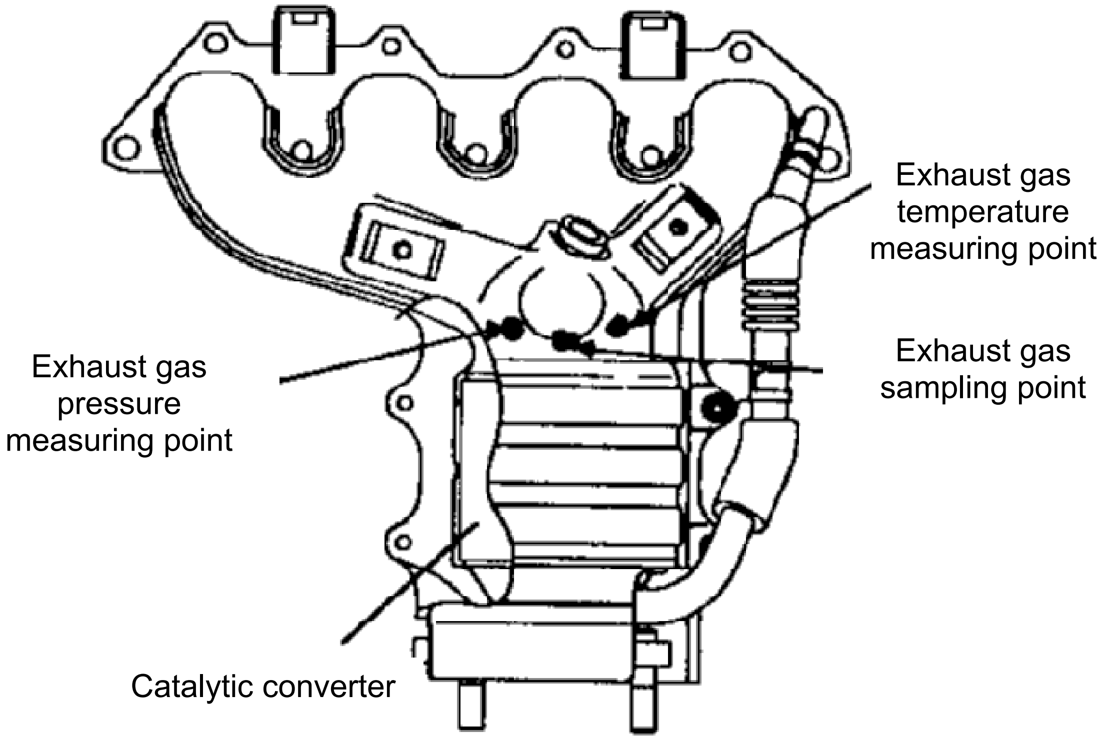


Exhaust System Components



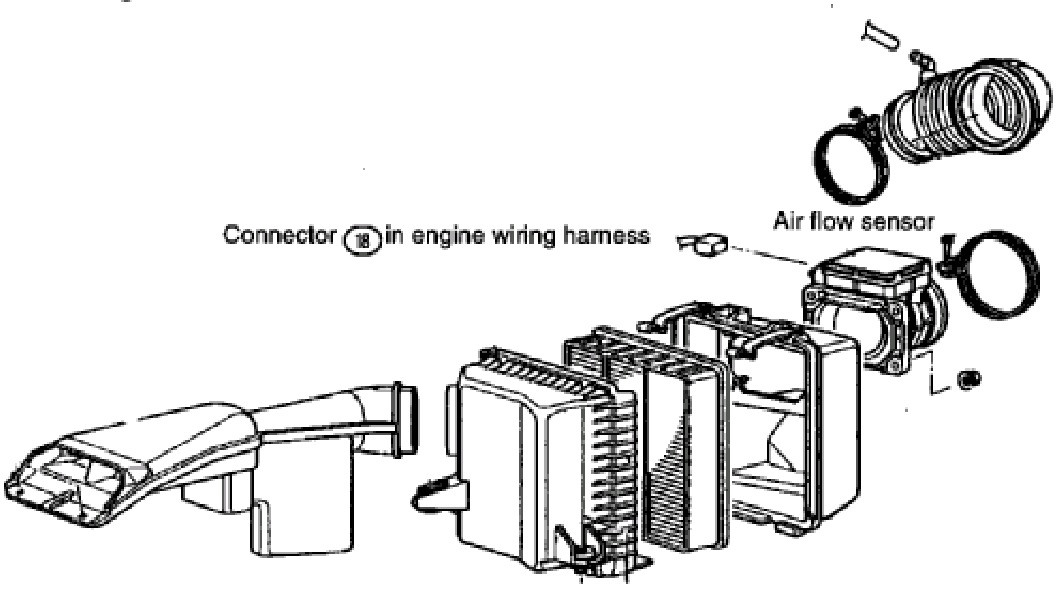
Appendix 15

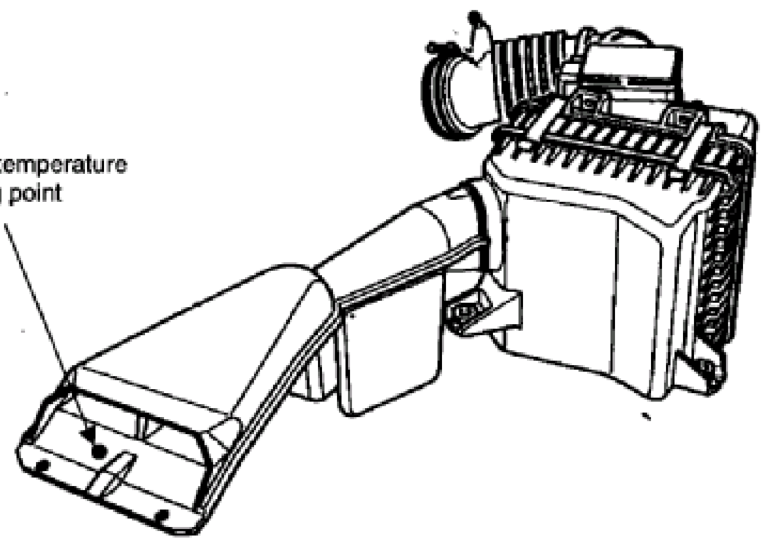
Positions of Exhaust Sensors



Appendix 16

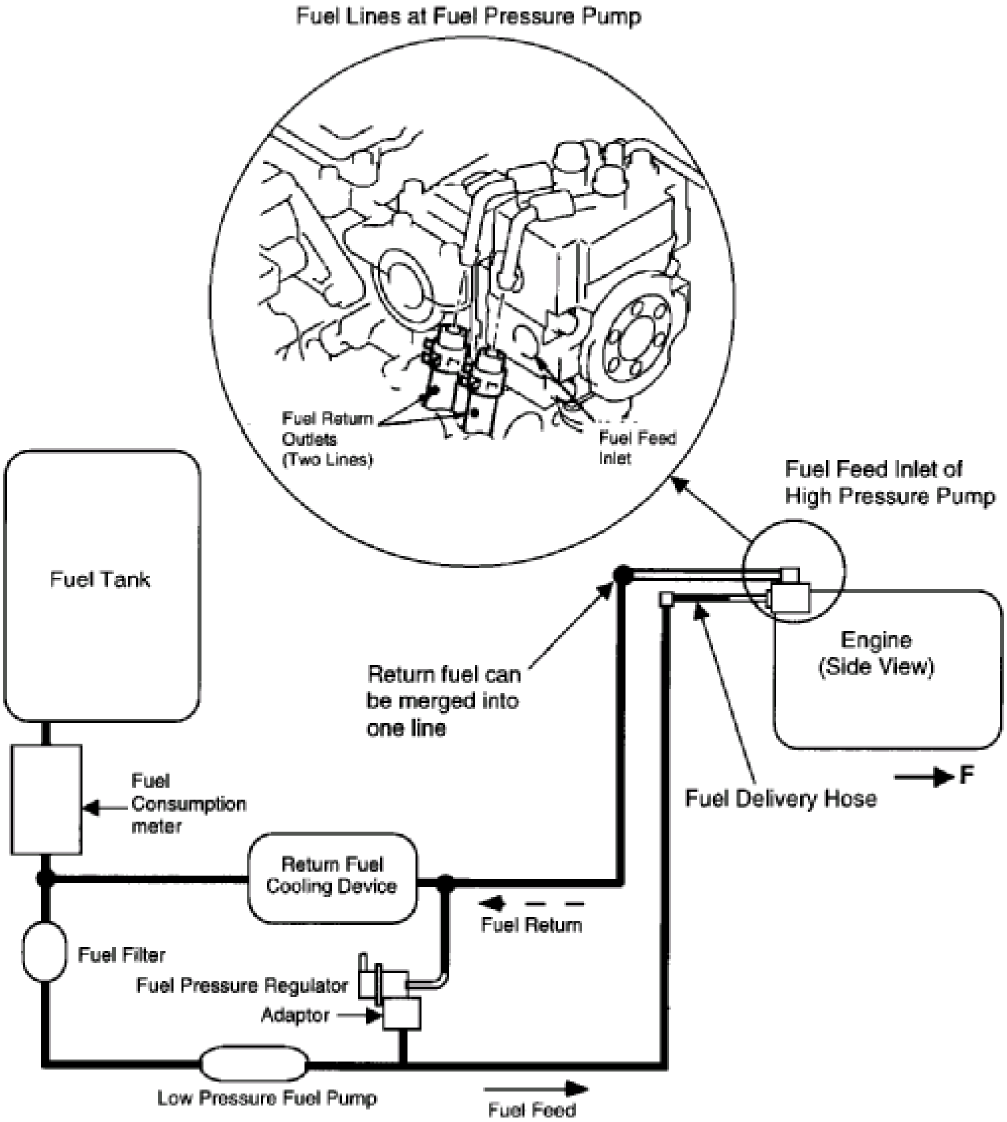
Air Intake System





Appendix 17

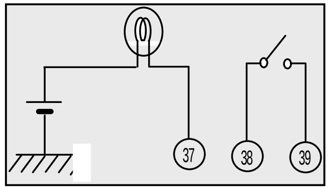
Fuel System

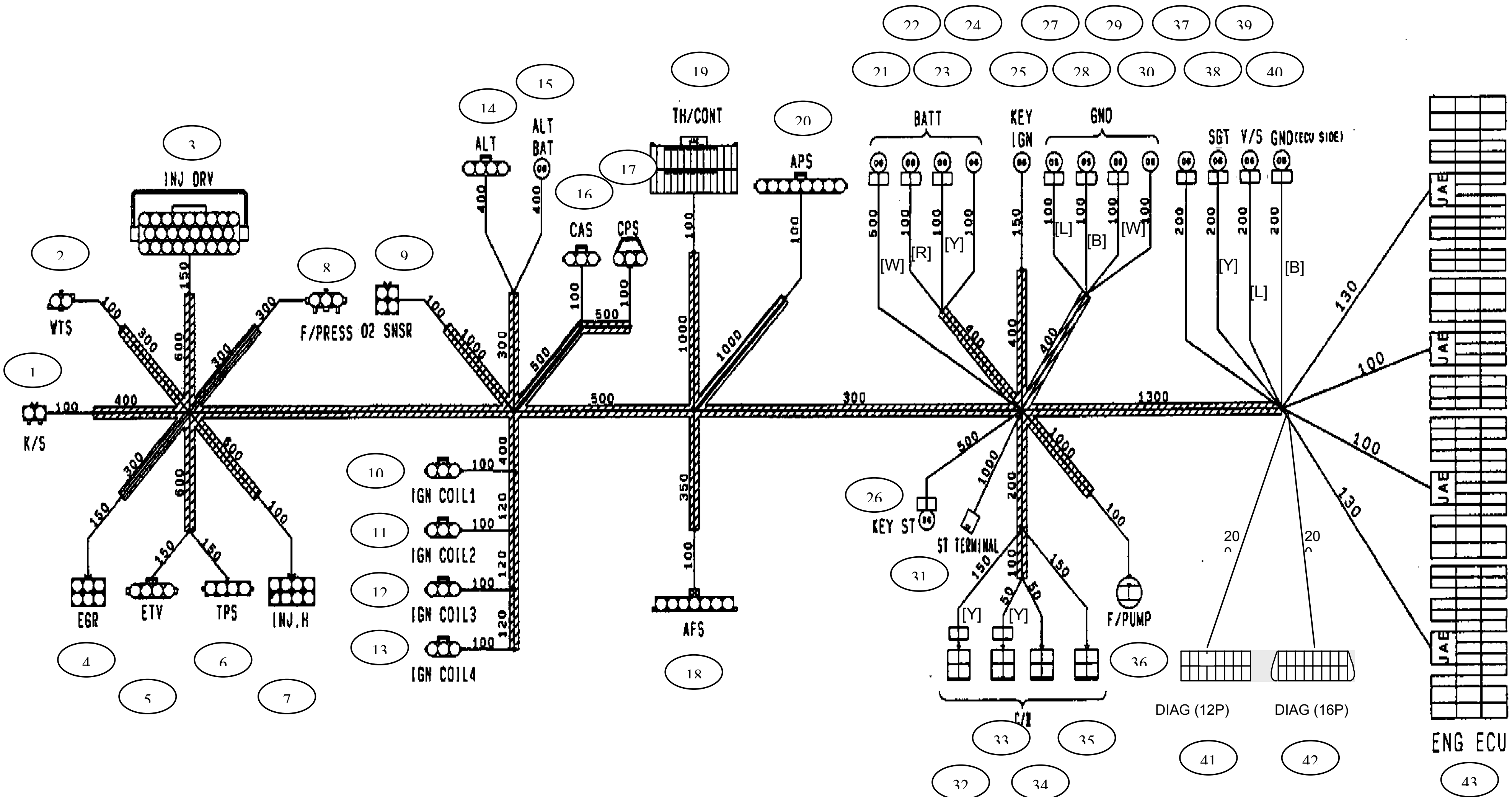


Appendix 18

Wiring Diagram

Additional Wiring
a. A lamp bulb (12 V-1.4 W max.) should be installed between the No.37 and the battery positive terminal.
b. A combustion mode select switch needs to be installed between the No. 38 and No.39 connectors.





Appendix 18 (cont.)

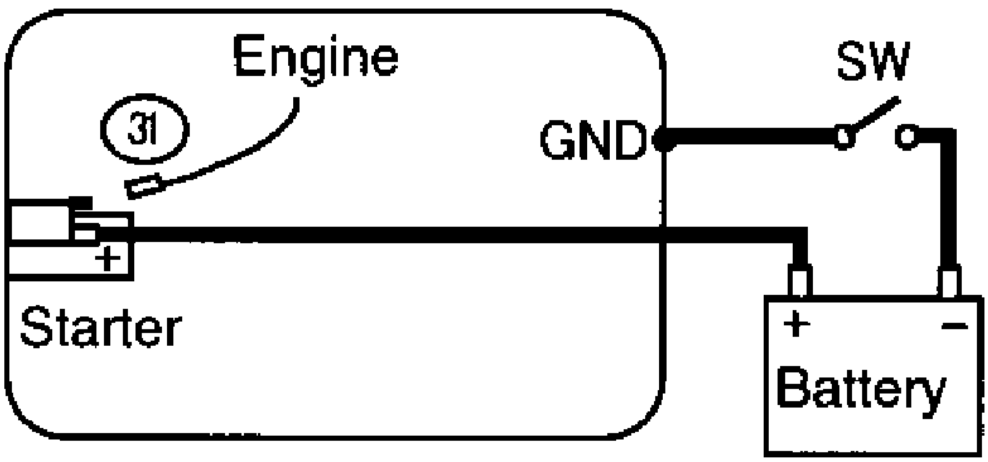
No.	Name of Connector	No.	Name of Connector	No.	Name of Connector
1	Knock Sensor	18	AFS (Air Flow Sensor)	32	Control Relay (ETV) [Y]
2	Engine Coolant Temperature Sensor	19	Throttle Controller	33	Control Relay (Fuel Pump) [Y]
3	Injector Driver	20	APS (Accelerator Pedal Position Sensor)	34	Control Relay (ECI)
4	EGR Motor	21	Battery (Alternator) [W]	35	Control Relay (Injector)
6	TPS	22	Battery (Injector) [R]	36	Fuel Pump
7	Injector Harness	23	Battery (ETV) [Y]	37	Engine Check Lamp
8	Fuel Pressure Sensor	24	Battery (Backup)	38	Combustion Mode Select Output [Y]
9	Oxygen Sensor	25	Ignition Switch / Ignition	39	Combustion Mode Select Input [L]
10	Ignition Coil - #1	26	Ignition Switch / Starter [L]	40	GND ECU [B]
13	Ignition Coil - #4	27	GND (Engine) [L]	41	DIAG (12P)
14	Alternator	28	GND (Engine) [B]	42	DIAG (16P)
15	Alternator “B” Terminal	29	GND ETV [W]	43	ECU
16	CAS (Crank Angle Sensor)	30	GND (Injector)		
17	CPS (Camshaft Position Sensor)	31	Starter Terminal		

Remarks:

1. The length of each branch wire is indicated by a numerical value next to the wire (Branch wires using a bullet terminal may be extended or shortened where required).
2. Connect No. 21, 22, 23, and 24 connectors (batteries) to the battery positive terminal.
3. Ground No. 27, 28, 29, and 30 connectors (GNDs) to the engine body.
4. Connect No. 40 connector (GND for the ECU) to a ground near the ECU.
5. Connect No. 25 and 26 connectors to ignition switch / ignition and ignition switch / starter.
6. The lead wire to No. 36 connector (fuel pump) may be extended where required.
7. Use the lamp installed between No. 37 and battery positive terminal to detect system failure.
8. Use the combustion mode select switch installed between No. 38 and No.39 to select engine combustion modes.
9. The same-shaped terminals are distinguished by color tape attached to them.
10. The color codes are: [B]: Black [L]: Blue [R]: Red [W]: White [Y]: Yellow

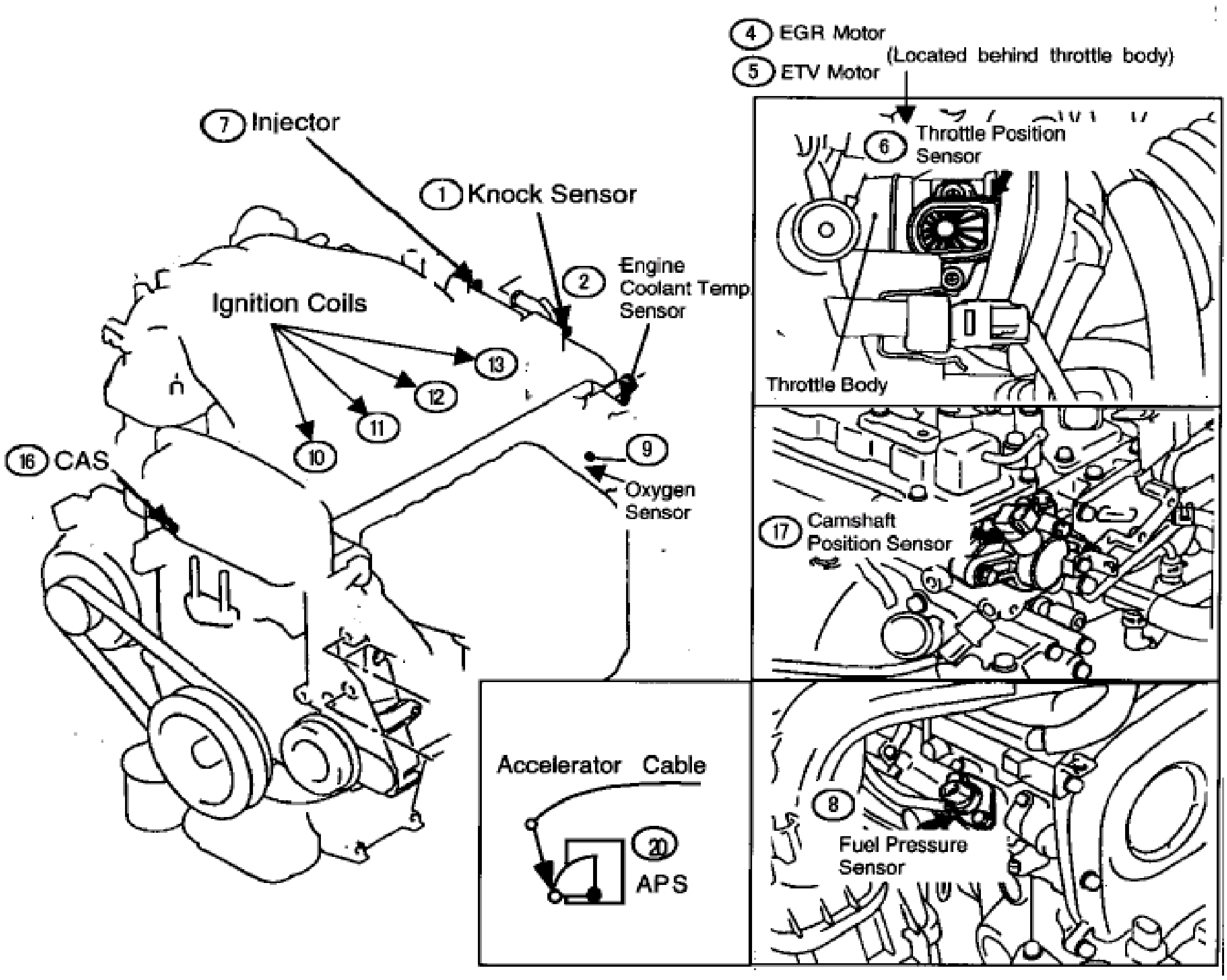
Appendix 19

Starting Circuit

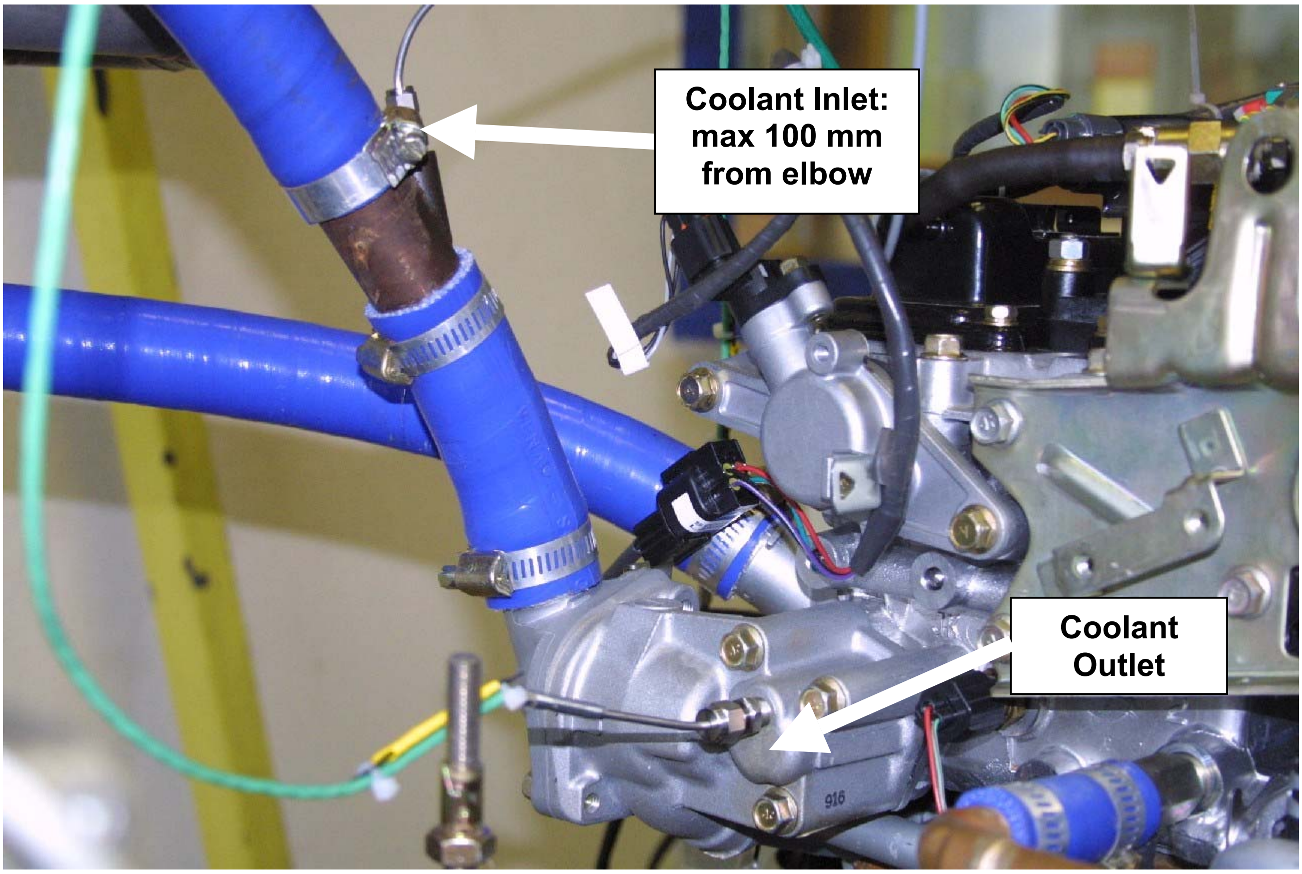


Appendix 20

Wiring loom connections

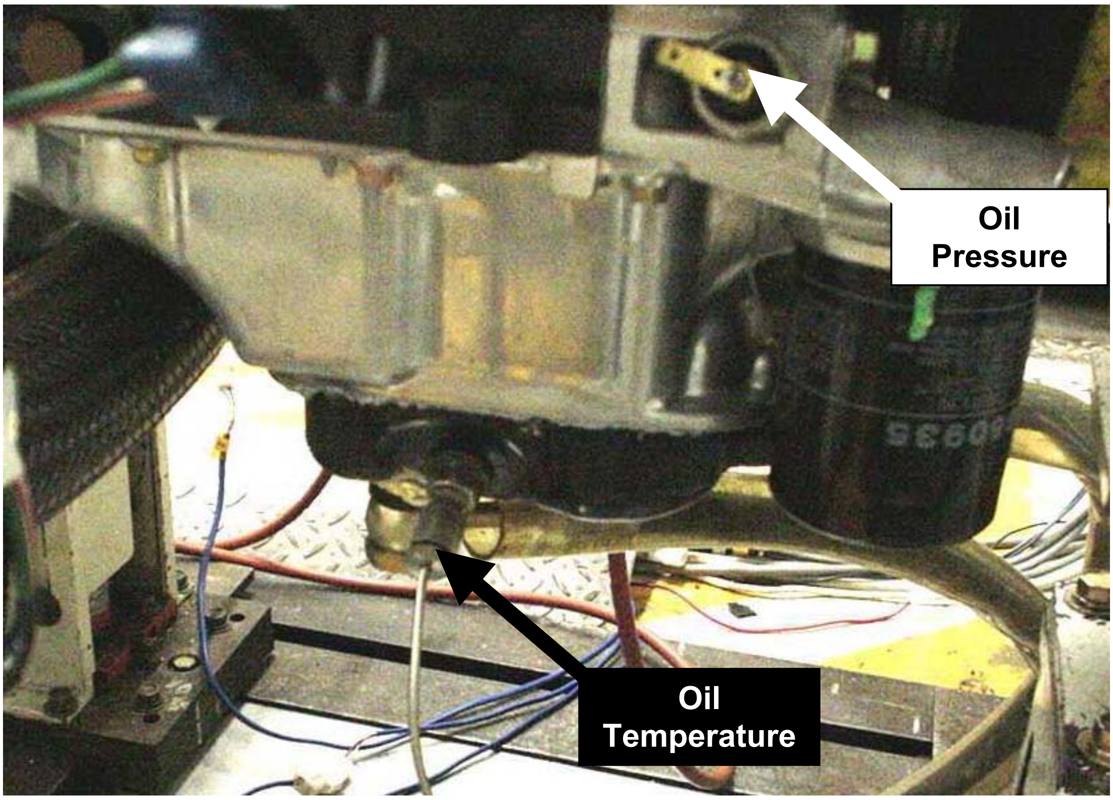


Coolant Measuring Points



Appendix 22

Oil Temperature and Pressure Measuring Points



Appendix 23

Evaluation Photographs

Piston Top

Cylinder Head Bottom

Inlet Valves

Intake Ports

Injector

Injector nozzle

Appendix 24

Cylinder Block Protective Plate

Appendix 25

Scraping Deposits from Piston Top

Appendix 26

Collecting Deposits with Vacuum Cleaner

Appendix 27

Cylinder Block Protective Plate

Appendix 28

Scraping Deposits from Combustion Chamber

Appendix 29

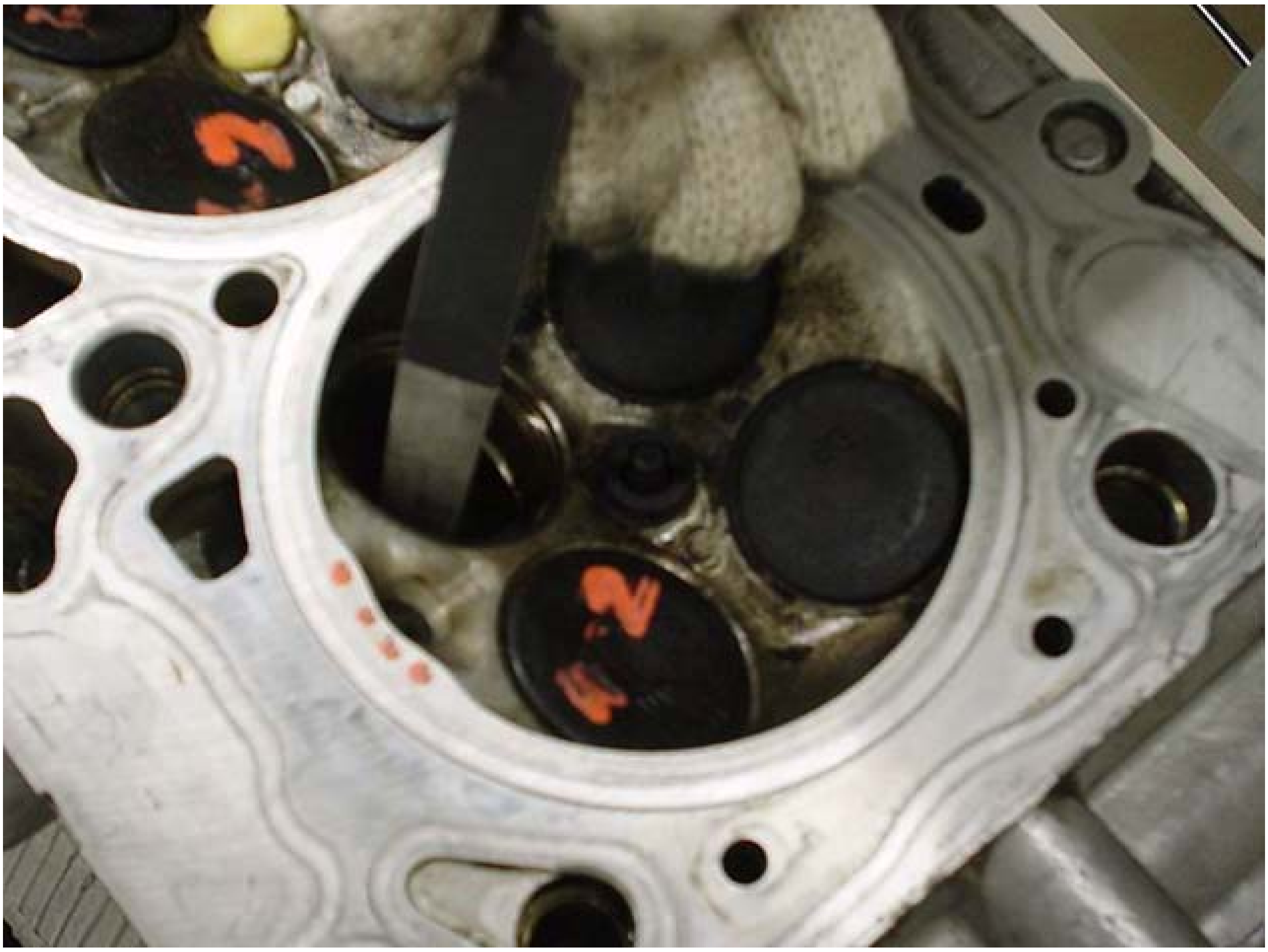
Collecting Deposits with Vacuum Cleaner

Appendix 30

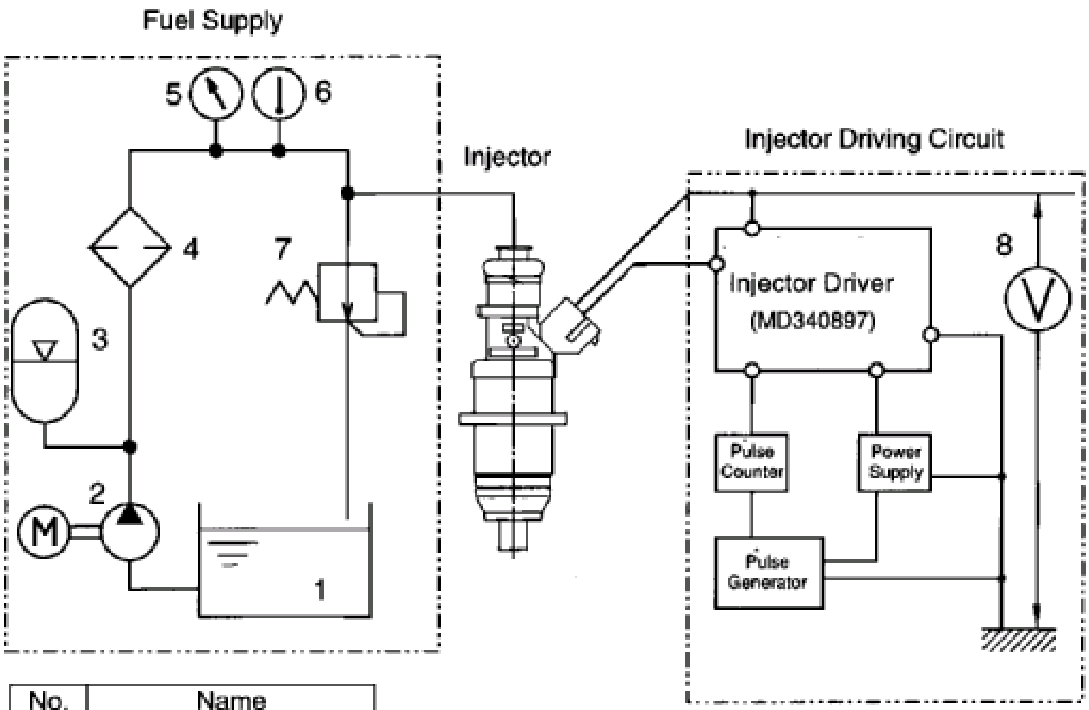
Intake Port Deposit Collection Method

Appendix 31

Removing Inlet Port Deposits



Injector Testing Devices



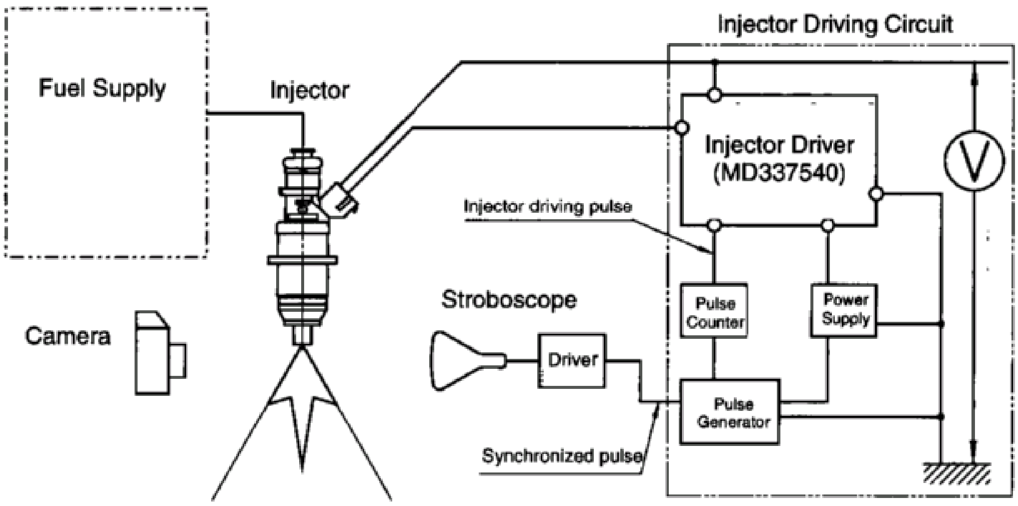
No.	Name
1	Test fluid tank
2	Fuel pump
3	Accumulator
4	Filter
5	Pressure gauge
6	Thermometer
7	Pressure regulator
8	Voltmeter

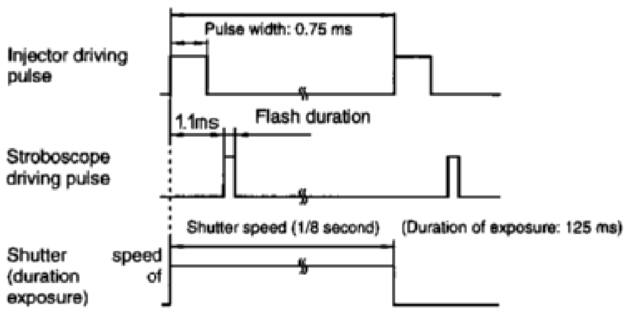
*Note: For the terminal locations on the iniector

Note: For the terminal locations on the injector driver refer to Appendix 35.

Appendix 33

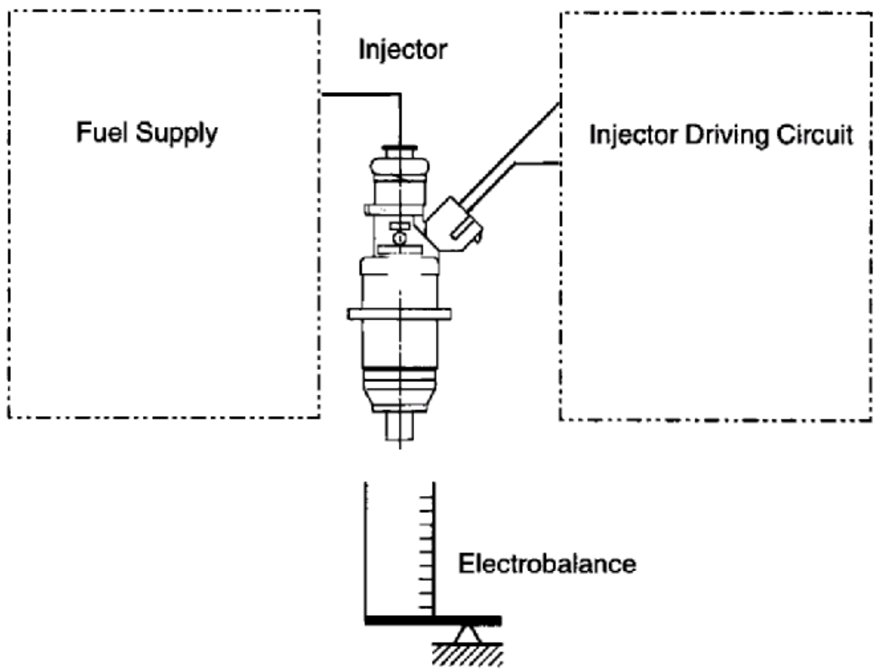
Injector Spray Pattern Equipment



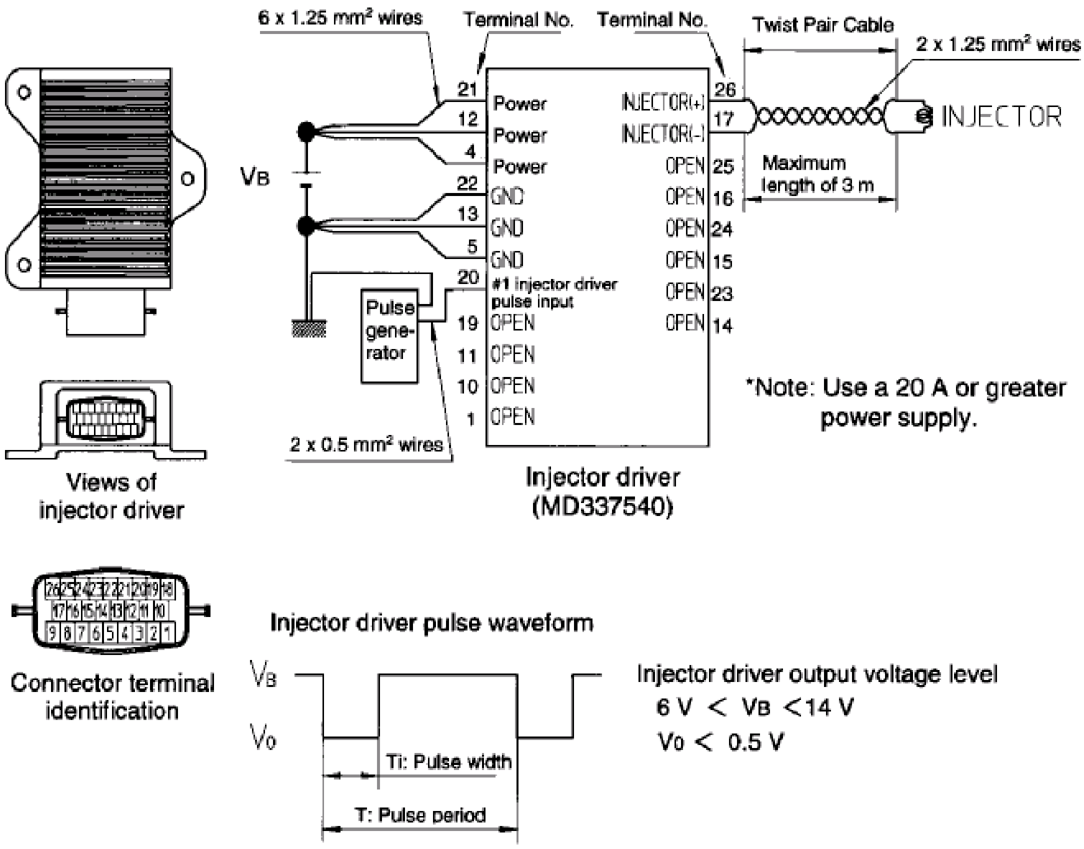


Appendix 34

Injector Flow Rate Equipment



Injector Driver Wiring Diagram



Appendix 36

Injector Dimensions

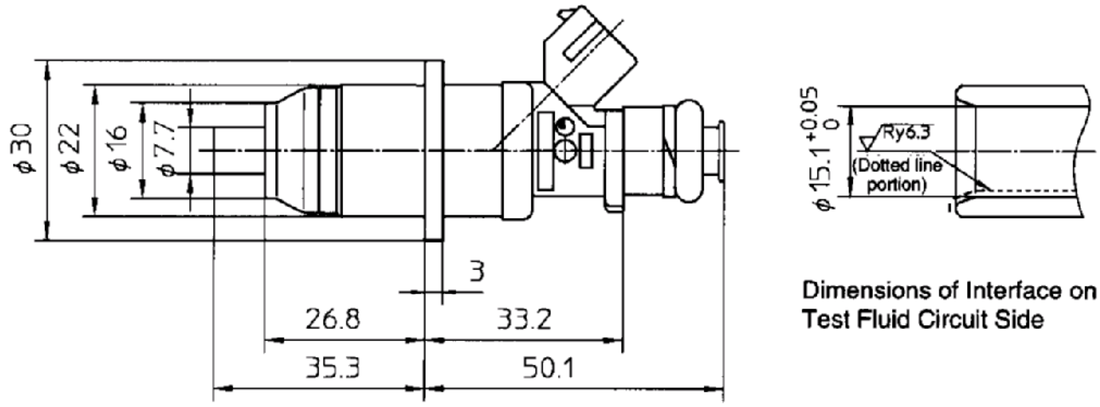


Fig. 26 Mounting Dimensions of Injector

Appendix 37

CEC Reference Oil CEC RL-213

RL 213/1

Characteristics	Method	Value Unit
SAE grade		5W-30
Density @ 15°C	ASTM D4052/IP365	846.4 gcm-3
Flash Point	ASTM D92/IP36	242 °C
Pour Point	ASTM D97/IP	15 °C
Kv @ 100°C	ASTM D445/IP71	12.07 mm2s-1
Kv @ 40°C	ASTM D445/IP71	73.08 mm2s-1
VI ASTM	D2270/IP226	163
CCS Visc. @ °C	ASTM D5293/IP383	2820 mPas
Brookfield Visc. @ °C	ASTM D2983/IP267	mPas
MRV °C	ASTM D4684	13000 Pas
Noack volatility	CEC L-40-A-93	6.9 % mass
High temp. High shear	CEC L-36-A-90	3.51 mPas
TBN (perchloric)	ASTM D2896/IP276	8.8 mg KOH g-1
TAN	ASTM D664/IP177	2.7 mg KOH g-1
Sulphated ash	ASTM D874/IP163	1.12 % mass
Zinc	ASTM D5185 (ICP)	0.1603 % mass
Phosphorus	ASTM D5185 (ICP)	0.0933 % mass
Calcium	ASTM D5185 (ICP)	0.1930 % mass
Magnesium	ASTM D5185 (ICP)	0.0483 % mass

Blend quantity	4000litres
Container sizes	50 kg / 59 litres
Available from	ISP, Salzbergen, Germany
Data sheet prepared by	Dr. U. Böcker, ISP
Date	June 1999

Appendix 38

Report Format

The following pages show the format for recording test results and test operating conditions.

Test Report

1. Test Conditions:

Date: ……...……………………………………………………………………….

Tested by: …………………………………………………………………………….

Engine type	Mitsubishi 4G93□GDI
Fuel	
Additive	
Engine oil	RL 213

Test pattern: …………………………………………………………………………….

…………………………………………………………………………….

…………………………………………………………………………….

…………………………………………………………………………….

Test No.: …………………………………………………………………………….

Test period: …………………………………………………………………………….

2. Summary of Test Results

(1) Injector flow (static)

(Unit: %)

Cylinder	#1	#2	#3	#4	Average
Flow rate change					

(2) CCD

Total weight g(Unit: g)

Cylinder			#1	#2	#3	#4	Average
Piston top							
Cylinder head							
Others	Cylinder liner						
	Gasket						
	Flame-face of intake valve	Front					
		Rear					
		Total					
	Flame-face of exhaust valve	Front					
		Rear					
		Total					
	Others Total						
CCD Total							

(3) IVD

Total weight g(Unit: g)

Cylinder		#1	#2	#3	#4	Average
Intake valve	Front					
	Rear					
	Total					
Intake port	Front					
	Rear					
	Total					
IVD Total						

Test No……………………..

3. Engine Operating Data

3.1 Fuel/oil consumptions

(1) Fuel consumption

Total ____ L/test

(2) Engine oil consumption

Total ____ g/test

3.2 Compression pressure   Unit: MPa

Cylinder	#1	#2	#3	#4	Engine speed rpm
Initial value					

3.3 Engine operating conditions

No.	Measuring item	Running time		
		0.5h	5h	50h
1	Engine speed□ (min^{-1})			
2	Torque (Nm)			
3	Intake manifold pressure (kPa)			
4	Intake air temperature (degC)			
5	Coolant outlet temperature (degC)			
6	Coolant inlet temperature (degC)			
7	Coolant flow-rate (L/min)			
8	Engine oil temperature (degC)			
9*	Engine oil pressure (kPa)			
10	Fuel consumption (L/h)			
11	Fuel inlet temperature (degC)			
12*	Fuel pressure (kPa)			
13	Exhaust gas pressure (kPa)			
14	Exhaust gas temperature (degC)			
15	Blow-by gas flow (L/min)			
16	Air-fuel ratio			
17*	Exhaust gas CO (%) concentration CO_2□ (%) □□□□□□□□ THC (ppmC) □□□□□□□□ NOx (ppm)			
18	Steam partial pressure (kPa)			
19	Barometric pressure□□ (kPa)			
20*	Ignition timing□□□ (deg. BTDC)			

*Note: Measure items marked * as necessary.

Test No……………………..

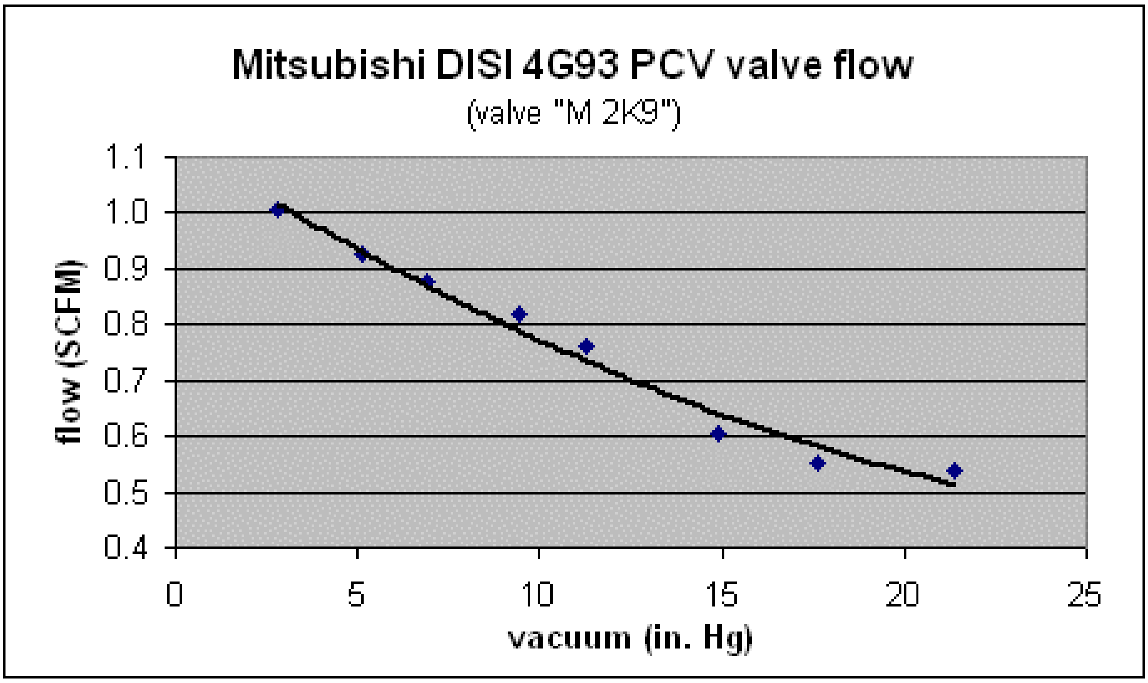
Cylinder	Piston top	Cylinder head
#1		
#2		
#3		
#4		

Test No……………………..

Cylinder	Intake valve	Intake port
#1	Front Rear	Front Rear
#2		
#3		
#4		

Appendix 39

Typical Flow Characteristics of PCV Valve



Appendix 40

Measurement Location for Post EGR Thermocouple