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AFTERMARKET CYLINDER HEAD TESTS ON MITSUBISHI PAJERO

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SUMMARY

This report presents performance, fuel consumption and emissions test results for a 1991 Mitsubishi Pajero following rebuilding of its original 4D56T diesel engine. The tests compare engine performance after fitting original and aftermarket cylinder heads, and were designed and carried out by staff of the Energy and Fuels Research Unit (EFRU) of the University of Auckland, New Zealand. The work was sponsored by David Britton of Innovative Mobility (NZ) Limited, trading as Steinz Manufacturing, to investigate claims that the vehicle's performance was adversely affected by fitting a substitute aftermarket replacement cylinder head rather than an approved Original Equipment Manufacturer (OEM) product.

The test program consisted of snap acceleration opacity measurements, power tests, fuel consumption and emissions measurements. The fuel consumption and emissions tests were conducted to international Japanese 10.15 and Australian/American IM240 test cycles.

The findings were that with the aftermarket cylinder head in place the vehicle showed a significant decrease in power (30% to 56% from 2500 to 4000 rpm) and significant increases in all main exhaust emissions species with the exception of oxides of nitrogen. Fuel consumption also increased significantly (23% for the drive cycles combined).

Snap acceleration opacity tests showed a decrease in exhaust opacity with the aftermarket head installed, possibly due to a high proportion of injected fuel remaining un-combusted.

During power testing with the aftermarket head at an engine speed of 4000rpm, exhaust gas temperatures approximately 50mm downstream of the turbocharger rapidly approached 700°C, which prompted test abandonment for fear of engine damage.

Both heads were examined by EFRU staff under the guidance of David Britton, the primary observable difference being a 1.95cc (~10%) reduction in the aftermarket head pre combustion chamber assembly volume compared to the OEM cylinder head. Whilst otherwise appearing identical, the variation in engine performance should not be attributed to pre combustion chamber assembly volume differences alone unless confirmed by a further detailed evaluation of both heads.

CONTENTS

1.0 OBJECTIVE

The objective of the testing detailed in this report was to determine the differences in performance between two cylinder head configurations when installed on the same vehicle.

2.0 VEHICLE DETAILS

Make:	Mitsubishi	Transmission:	Automatic, tested in rwd mode
Model:	Pajero	Engine:	4D56T 2.5L I4, IDI,
Year:	1991		Inter-cooled & turbocharged diesel
Registration:	UJ1507		
Odometer as at testing with head 1.		215729 km	
Odometer as at testing with head 2.		215840 km	

3.0 TEST EQUIPMENT AND PROCEDURES

3.1 Testing schedule

Steinz Manufacturing supplied the test vehicle on the 9^{th} of July 2004 with head one installed and subsequently on the 12^{th} with head two installed. The vehicle was tested as supplied on both occasions and following dynamometer testing each head was marked by a member of the EFRU staff. Cylinder head removal and replacement was performed off premises by Steinz and promptly returned to EFRU staff for examination.

- Head one is believed to be the correct Original Equipment Manufacturer part.
- Head two, identified by the letters "AMC" cast in, is believed to be an aftermarket replacement part claimed by its Manufacturer to suit 4D56T engines to 1994; the NZ reseller claims suitability to "4D55/56T" engines.

3.2 Test Equipment

The tests were conducted at the University of Auckland's Vehicle Research Facility. A full flow dilution tunnel and constant volume sampling system (CVS) were utilised. Non-dispersive infrared analysers measured carbon monoxide (CO) and carbon dioxide (CO_2) concentrations, a heated flame ionisation detector measured total unburned hydrocarbons (THC) and a heated chemiluminescent analyser measured oxides of nitrogen (NO_x). All analysers are laboratory grade instruments. Gravimetric filter samples were taken to determine particulate (PM) emissions. The emissions equipment is in general compliance with the requirements of vehicle emission certification laboratories as specified in European and United States regulations.

The vehicle was operated on a chassis dynamometer with fully programmable simulation of aerodynamic and rolling resistances (jointly comprising the "road load") and inertia simulation with flywheels. In addition a Celesco model 300 smoke meter was used to measure vehicle exhaust gas opacity. Temperature and pressure measurements were taken using k-type thermocouples and a Teltherm Bourdon-tube pressure gauge.

3.3 Test Procedures

A variety of test procedures were used for each configuration included snap acceleration to SAE J1667, power testing over the working speed range and emissions testing in accordance with the Japanese certification 10.15 mode drive cycle followed by the US legislated inspection and maintenance drive cycle IM240. The later drive cycle tests will be referred to as the JAP10.15 and IM240 respectively; details of both test cycles are provided in Table 1.

Table 1 – Test Cycle Characteristics

	Jap 10.15	**IM240**
Start Condition	Hot	Hot
Duration (s)	660	240
Distance (km)	4.2	3.2
Av. Speed (km/h)	22.7	47.3
Max Speed (km/h)	70	91
Max Accell. (m/s^2)	0.81	1.5
% idle	32.1	4.5

Three repeat tests of each cycle were conducted for the vehicle with each engine/cylinder-head configuration. Prior to each drive cycle the vehicle was run on the dynamometer either at 60km/hr and light load or through a warm up drive cycle until the vehicle reached normal operating temperature. In addition supplementary examinations and tests were conducted including:

- Establishment of pre combustion chamber cup port and cavity volumes, using a chemists burette and custom cc metering plate
- Establishment of pre combustion chamber assembly volume (injector, glow plug, and precom cup in place, head inverted and chamber assembly filled to the cylinder head/block gasket face).
- Steady state power testing and recording of exhaust gas temperature, pre combustion chamber temperature, and inlet air pressure.

The vehicle was also tested using the snap acceleration procedure to assess visible smoke emissions as specified in SAE standard J1667. This is used in several countries as an inspection and maintenance test procedure. The test is usually performed by rapidly and fully depressing the accelerator with the vehicle transmission in neutral until the governed speed is reached, and measuring peak exhaust opacity. In this case, however, the driver was instructed to lift off the accelerator when the engine reached 4000 rpm, just short of the 4500 rpm factory engine speed limit or redline.

4.0 RESULTS

4.1 Drive cycle emissions and fuel consumption results

The average exhaust emissions in grams per kilometre taken from three repeats of each drive cycle are included in table 1. Note that F.C. is fuel consumption in litres per 100 kilometres, and is calculated from the carbon based emissions species present in the exhaust.

Table 1. Emissions results for Jap 10.15 and IM240 drive cycles

Emissions species	Jap 10.15			IM240		
	Head 1	Head 2	% change	Head 1	Head 2	% change
CO (g/km)	0.574	2.45	326%	0.697	5.04	624%
CO2 (g/km)	338	387	14%	301	395	31%
CH4 (g/km)	0.077	0.630	718%	0.064	0.699	986%
NOx (g/km)	2.62	0.872	-67%	1.95	0.816	-58%
F.C. (l/100km)	12.5	14.5	16%	11.2	15.0	34%
PM filter (g/km)	0.866	1.80	108%	1.09	3.69	238%

During the IM240 drive cycle with cylinder head two fitted the vehicle was not able to match the rate of acceleration required by some sections of the cycle due to insufficient engine power.

4.2 Volume measurement results

The results obtained from measuring the number one cylinder pre combustion cup and associated cavity of each cylinder head are shown below in table 2. Note that volumes were obtained in both disassembled and assembled states.

Table 2. Chamber volumes for No. 1 cylinder on each cylinder head.

Volume description	Head 1	Head 2
Pre combustion chamber cup alone, total volume (ml)	12.10	11.50
Head chamber fully assembled with pre combustion cup fitted (ml)	19.75	17.80

4.3 Steady state power testing results

The results obtained by power testing of the vehicle with each cylinder head configuration at steady speed and full throttle are given in table 3 and plotted in figure 1.

Table 3. Steady state power test results

RPM	Power (kW)	
	Head 1	Head 2
2500	42.4	29.8
3000	45.3	29.9
4000	49.4	21.8

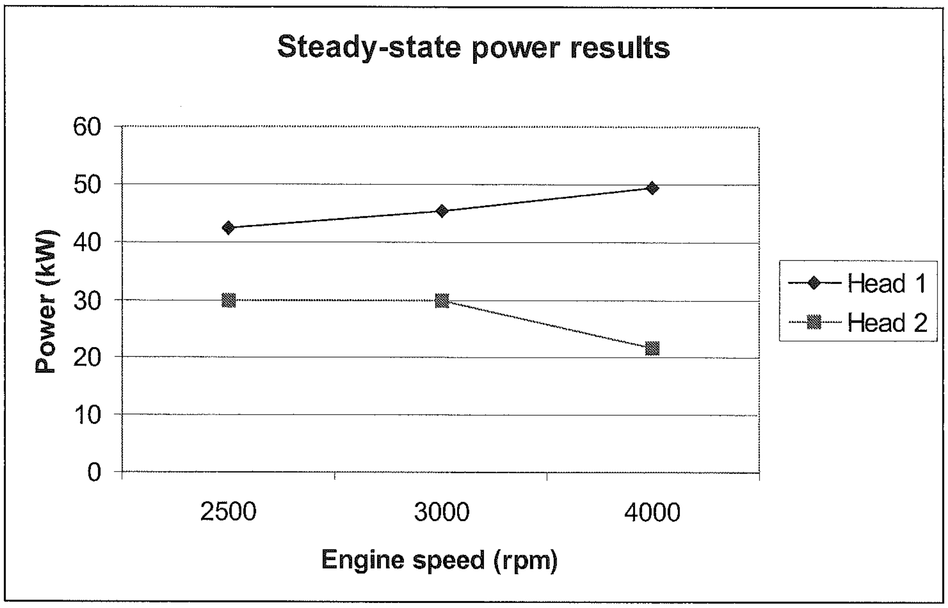

Figure 1. Power vs. engine speed results for the vehicle with the two cylinder head configurations

Temperatures and pressures were recorded for head two only; the results are shown below in table 4. Note the exhaust gas temperature at 4000 rpm was still increasing when the test was aborted for fear of engine damage.

Table 4. Steady state full throttle temperatures and pressure recorded with head two.

RPM	Pre-comb chamber temp (°C)	Inlet press (bar)	Exhaust gas temp (°C)
2500	464	0.8	662
4000	515	0.82	680*

* Temperature still climbing at time of reading

4.4 Snap acceleration exhaust opacity test results

Snap acceleration test results are shown in table 5 and the results given in k (m^{-1}) values, which represent a light absorption coefficient.

Table 5. Snap acceleration test results in k (m^{-1}) values

Exhaust opacity k (m^{-1})	
Head 1	7.98
Head 2	6.17

5 DISCUSSION

Several significant changes in vehicle performance were recorded when the vehicle was re-tested with cylinder head two installed.

The drive cycle results showed a significant increase in all emissions species with the exception of oxides of nitrogen. An increase in overall carbon emissions demonstrates poor combustion efficiency, as confirmed by a significant loss in power. The lower NOx emissions produced with head two also suggest reduced peak combustion temperatures and pressures.

The power losses illustrated in figure 1 further demonstrate compromised combustion efficiency, which caused the driver to push further on the accelerator in order to meet drive cycle acceleration and power demands.

The snap acceleration opacity test is employed internationally to detect out of tune vehicles. In this case, the fitting of head two yielded lower results compared with head one, likely due to the passage of greater quantities of unburned hydrocarbons.

The smokemeter used in testing functions by passing a light beam through the exhaust gas and measuring the proportion of light extinguished by the passing gas. Un-combusted hydrocarbons would contribute less to light extinction than would the greater quantities of soot produced by semi combusted fuels produced during similar snap acceleration tests under standard engine condition and test conditions.

The port cross sectional areas of pre combustion chamber cups fitted to head two were approximately 2.5% less that the OEM precom cups of head one.

When comparing pre combustion chamber assembly volumes, that of head two possessed approximate 1.95cc or 9.9% less than head one, in agreement with Steinz Manufacturing's own findings of between 1.8cc and 2.0cc. Steinz Manufacturing believes the reduction in pre combustion chamber assembly volume and port cross sectional areas are the only functional differences between the two cylinder heads,

As no temperature or pressure results were obtained for the vehicle when fitted with head one, no comparison is possible with the data temperature and pressure data obtained with head two.

6 CONCLUSIONS

- Averaged across two drive cycles, when fitted with the aftermarket cylinder head (head two) and compared with the OEM head (head one), the vehicle produced significantly higher emissions of:
    - carbon monoxide (467% increase)
    - carbon dioxide (21% increase)
    - non-combusted hydrocarbons (821% increase)
    - particulate matter (172%).
- When fitted with head two the vehicle showed a reduction in oxides of nitrogen exhaust emissions which averaged 64% across the drive cycles.
- When fitted with head two the vehicle required approximately 23% more fuel to complete the same drive cycles compared to head one. Fuel consumption is calculated from the carbon-based emissions species present in the exhaust.
- When fitted with head two, power was reduced by 30% at 2500 rpm and 56% at 4000 rpm.
- When examined following the engine tests, the precombustion chamber assembly volume of head two was found to be approximately 1.95cc or 9.9% less than head one.
- Differences in fuel consumption, emissions and power output appear attributable to configuration differences between the two heads. Further measurement and testing would be required to confirm reduced precombustion chamber assembly volumes alone were responsible for the significant differences in measured results.