ORBITAL
AUSTRALIA PTY LTD
A.B.N. 56 008 764 654

4 Whipple St, Balcatta, 6021, Western Australia
PO Box 901, Balcatta, 6914, Western Australia

Website: www.orbitalcorp.com.au

Testing and Evaluation of the REVETEC X4 Version 2 Prototype Engine

Report to
REVETEC Holdings Ltd.

CONFIDENTIAL

This report is provided solely for the use of REVETEC Holdings Ltd.

Customer contact name	**Brad Howell-Smith**
Client reference	
Orbital project	**REV002**
Date	**31 March 2008**

TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

Orbital was engaged by Revetec Holdings Ltd. (Revetec) to test the brake performance of their prototype X4 Version 2 (V2) configuration engine at part load and at full load. The details of the configuration of the X4V2 engine related to the piston crank mechanism as tested are not reported here.

The part load testing was performed to measure the fuel consumption and engine out exhaust emissions of the engine when operating at speeds and loads associated with city and highway driving related to the European driving cycle (NEDC99). Five test points were identified including the 2000 rpm 200 kPa brake mean effective pressure (BMEP) world wide test point. The 18kW 2000 rpm point was included in the test points at the request of Revetec.

Full load testing was completed over the engine speed range suggested by Revetec from 1500 to 3500 rpm.

The 18 kW 2000 rpm test point was tested back to back at a stoichiometric air fuel ratio of 14.5:1 returning average brake specific fuel consumption (BSFC) of 237 g/kWh. At the request of Revetec, the engine was operated at an air fuel ratio leaner than stoichiometic of 15.2:1 returning average brake specific fuel consumption (BSFC) of 212 g/kWh, based on two back to back data records.

At full load, the engines torque ranged from 132.9 Nm (BMEP was 701.4 kPa) at 1500 rpm to a peak torque achieved at 3500 rpm of 176.1 Nm with the BMEP of 929 kPa. The full load data was corrected according to ISO 1585.

2 INTRODUCTION

The Revetec engine is a unique design that uses two counter rotating tri lobular cams and rollers to produce the reciprocating motion normally generated by a crankshaft and connecting rod in a conventional engine. The Tri-lobed cam profile can be tailored to generate different piston motions with respect to crank angle. The Revtec tri-lobe cam mechanism is shown in figure 2.1 below.

Figure 2.1. Revetec Tri-Lobe Cam Mechanism

Orbital was contracted by Revetec to test their 2.4 litre X4V2 engine in Orbital's engine dynamometer test facility and to supply independent test data of the full load performance and part load fuel consumption and exhaust emissions of the engine. Revetec subsequently supplied the complete X4V2 engine ready to run with exhaust and intake system fitted and the engine mounted onto a frame to aid installation at the Orbital engine dynamometer test facility. A Revetec representative was present for the entire engine testing to ensure the engine was operated to Revetec's requirements.

The test facility was set-up to enable the brake performance of the engine to be evaluated. Prior to engine testing, the test facility equipment to be utilised during the evaluation was calibrated, checked for leakage and to ensure all systems were operating correctly. At part load engine operation, the exhaust gas analysis was provided by the Horiba exhaust gas analysis bench enabling the brake specific

emissions to be determined along with the air fuel ratio based on a complete carbon and oxygen balance.

During the full load engine testing, the engine was only operated for approximately 5 seconds at each engine speed, fuel flow and exhaust gas emissions were therefore not measured. The power and torque measured at full load were corrected for atmospheric conditions according to ISO 1585.

While the configuration of the reciprocating mechanism of the engine is not reported here, it should be noted that the cylinder head configuration can be described as a conventional over head valve configuration with 2 valves per cylinder operated by a conventional camshaft, push rod and rocker arm system. Each cylinder head utilised two spark plugs per cylinder.

3 TEST CELL INSTALLATION

This engine was installed into a test cell at Orbital's engine dynamometer test facility. The test cell was fitted with a Schenk eddy current brake dynamometer, Ono-soki gravimetric fuel flow measuring equipment, Horiba series 20 exhaust gas analyser bench and an interface for the general test cell instrumentation and instrumentation fitted to the engine all of which was interfaced to Orbital's automated test cell data acquisition system. Oil and coolant were circulated through plate heat exchangers to maintain engine oil and coolant temperature. The engine was delivered to Orbital complete with a bypass thermostat system which was used to regulate coolant temperature. The engine was fitted with a 4 into 2 into 1 exhaust system; the sample point for the emissions bench was taken at the last 2 into1 junction.

Instrumentation was fitted to the engine enabled the following measurements.

- Oil temperature located in the sump
- Oil pressure
- Water temperature at coolant intake to the pump
- Water temperature at the coolant outlet after the bypass thermostat
- Water temperature at cylinder heads 1 & 2
- Manifold absolute pressure (MAP)
- Exhaust gas temperature located 50mm after the exhaust flange to engine interface on all 4 cylinders.
- Air intake temperature
- Fuel temperature
- Fuel exhaust gas analysis (Horiba series 20 bench)
- Air fuel ratio (Wide band UEGO (10 to 20 AFR))

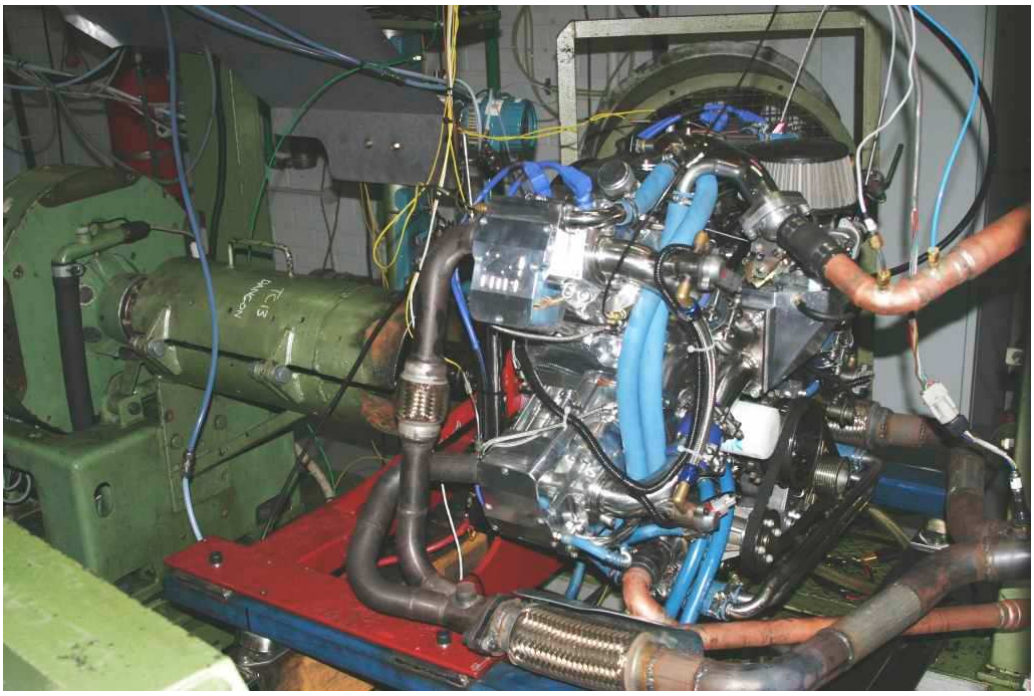


Figure 3.1. Test cell engine installation

Figure 3.2. Engine test cell control bench

The engine was fitted with conventional manifold fuel injection hardware and 2 spark plugs per cylinder. The fuel and ignition were controlled by a HALTECH E8 engine control system. Engine Maps existed for operating the engine and the control system could be adjusted to offset both the fuel and ignition map set points. This allowed optimization of the fuel level and ignition timing at each test point.

Fuel was supplied to the engine by the test cell fuel supply system which pumped fuel from the Ono-soki fuel measuring equipment through the engine fuel rail with the by pass fuel returning back to the Ono-soki, the difference therefore being the fuel used by the engine.

Figures 3.1 and 3.2 above show the engine installation into the engine test cell and the engine control bench with the Horiba exhaust gas analyser.

4 ENGINE TESTING

Engine testing included both part load and full load test points. The selection of the full load test points included from 1500 rpm to the maximum speed of 3500 rpm in 500 rpm increments. The maximum speed of the engine was defined by Revetec.

4.1 Determination of part load test points

The selection of the part load points for the engine evaluation was based on prior testing undertaken at Orbital on a similar sized engine in a vehicle. In this instance the vehicle was driven through the European Drive cycle (NEDC99) while recording the engine speed and load at one second intervals. Subsequent analysis of this data determined the frequency of certain speed and load combinations where the engine spent the largest portion of its time during the drive cycle test. These combinations define operating points for the engine where best fuel consumption is required to achieve good fuel consumption over the European drive cycle. Five of these points were selected as the part load test points for the evaluation of the X4V2 Engine one of which was the 2000 rpm 200 kPa BMEP “world wide mapping point”. The other four points were chosen as these represented the points where the engine spent the largest portion of time at during the vehicle driving cycle test.

Revetec had previously tested the engine at 2000 rpm, 18 kW (BMEP = 450 kPa). This speed load point was included in the test schedule shown as the last entry in Table 4.1. All the part load test points adopted for testing are shown in Table 4.1.

Engine RPM	Engine Load (BMEP, kPa)
850	15
1600	65
1800	190
2000	200
2200	65
2000	450

Table 4.1 - Part load test points

5 TEST RESULTS

5.1 Part load fuel consumption results

Not all the part load test points determined and shown in Table 4.1 were able to be tested back to back. Typically, data is only presented based on back to back tests with nominally the same test conditions when the result of both tests nominally produces the same result. The 2000 rpm 450 kPa BMEP part load test point has back to back test data. Two data sets are reported for this test point, one data set with the engine operated stoichiometrically and one data set with the engine operated lean of stoichiometry at an air fuel ratio of 15.2:1 as requested by Revetec. This data is presented in Table 5.1.1 below.

Based on Orbital's gasoline database, 14.5:1 is considered the stoichiometric air fuel ratio for pump gasoline used for engine testing. The octane rating of the pump gasoline used for testing the Revetec engine was 98 RON due to the 10:1 compression ratio of the engine. The full load BMEP at 2000 rpm was measured as 759 kPa. Note the first BSFC entry in Table 5.1.1 is an average of 236 and 239 g/kWh while the second entry is an average of 207 and 217 g/kWh.

Engine Speed (rpm)	Engine Load (BMEP (kPa)	Air Fuel Ratio(:1)	BSFC (g/kWh)
2000	450	14.5	237
2000	450	15.2	212

Table 5.1.1. Back to back part load fuel consumption

The data presented in Table 5.1.2 is from a single test only and further back to back testing is required to fully validate this data, however it is presented in order to provide a broader understanding of the capability of the engine.

Engine Speed (rpm)	Engine Load (BMEP (kPa)	Air Fuel Ratio(:1)	BSFC (g/kWh)
850	15	14.5	NA
1600	65	14.5	1568
1800	190	14.5	527
2000	200	14.5	490
2200	65	14.5	1120

Table 5.1.2. Single test part load fuel consumption

5.2 Part load exhaust emissions results

As with the part load fuel consumption data, the part load exhaust emissions results is presented based on data with back to back testing and results from a single point test with the same stipulations. Table 5.2.1 contains the average of the two back to back tests while Table 5.2.2 contains the single test result.

Engine Speed (rpm)	Engine Load (BMEP (kPa)	BSHC (g/kWh)	BSCO (g/kWh)	BSNOx (g/kWh)	Air Fuel Ratio(:1)
2000	450	5.8	33.0	11.6	14.5
2000	450	4.6	16.1	10.9	15.2

Table 5.2.1. Back to back part load exhaust emissions

Engine Speed (rpm)	Engine Load (BMEP (kPa)	BSHC (g/kWh)	BSCO (g/kWh)	BSNOx (g/kWh)	Air Fuel Ratio(:1)
850	15	NA	NA	NA	14.5
1600	65	38.3	159.9	20.6	14.5
1800	190	13	52.2	20.7	14.5
2000	200	11.2	54.1	18	14.5
2200	65	30.4	101.5	39.0	14.5

Table 5.2.2. Single test point part load exhaust emissions

5.3 Full load engine performance results

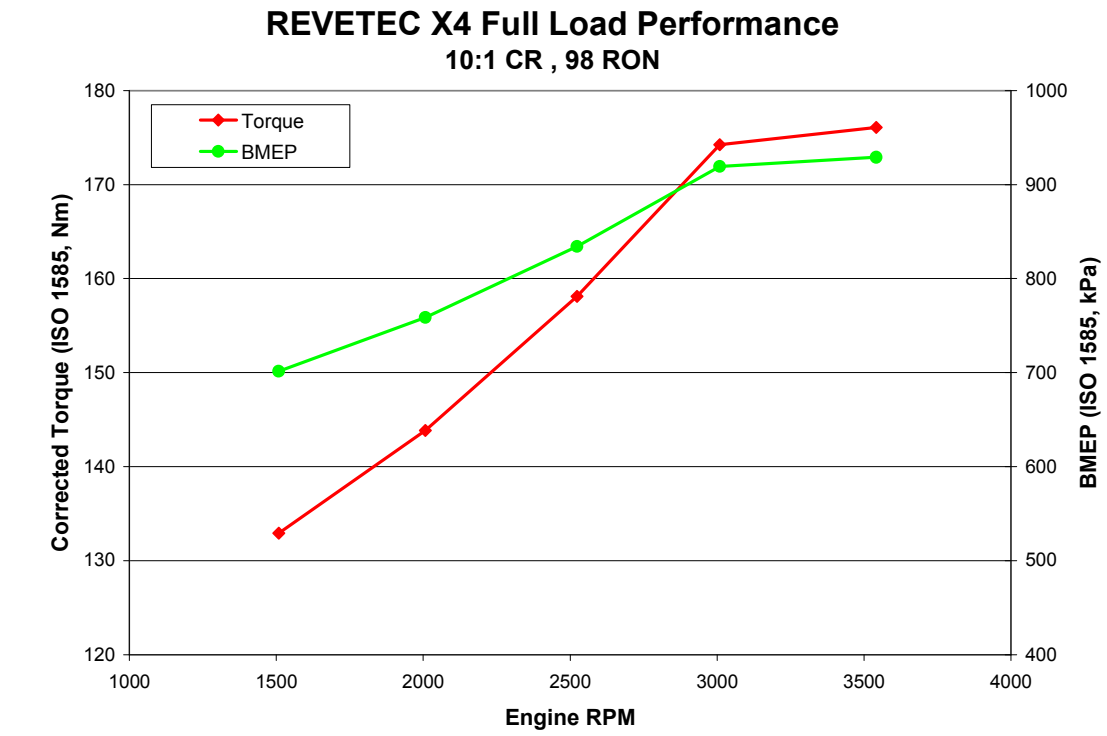
The full load testing of the Revetec engine was performed over the engine speed range as advised by Revetec. The data presented represents an average of approximately 5 seconds of operation at each of the speed points. The ISO 1585 correction was employed to correct for the variation in atmospheric conditions. During the full load testing, data was not logged for exhaust emissions or fuel flow rate due to the limited period of engine operation at each engine speed.

The engine was operated at an air fuel ratio richer than stoichiometric as is typical for full load engine operation for power and engine protection.

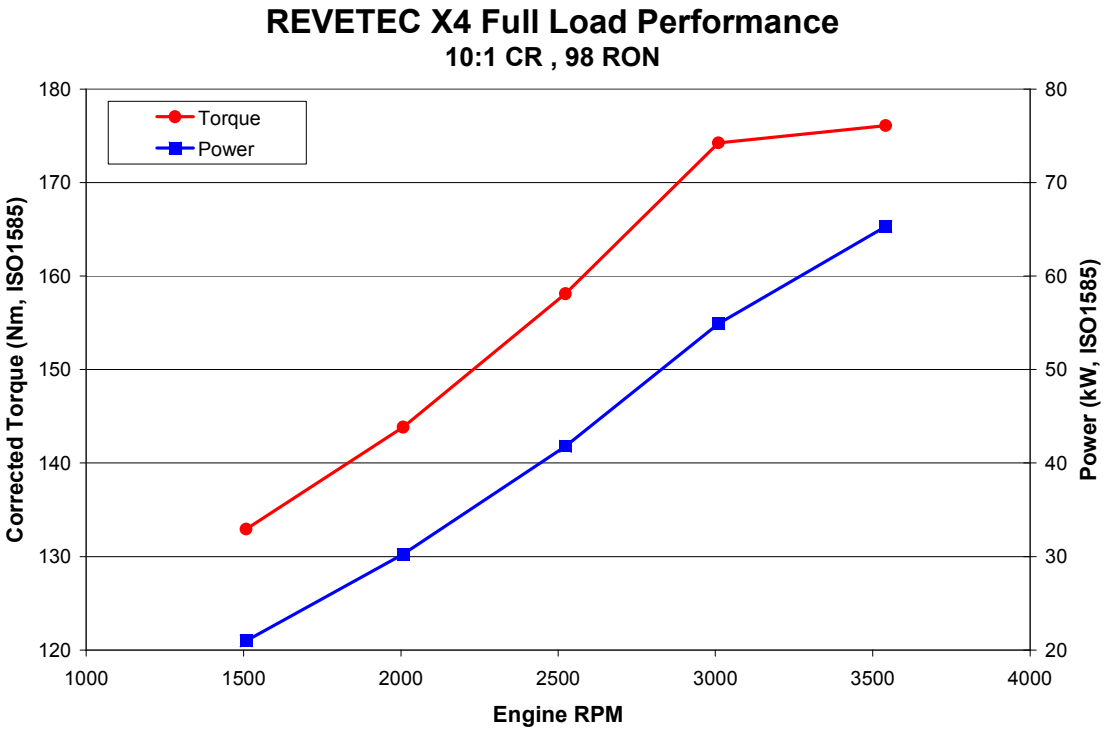
Graph 5.3.1 shows the full load torque and BMEP measured from the engine over the engine speeds tested. The BMEP ranged from 701 kPa to 929 kPa from the lowest to the maximum engine speed tested.

Graph 5.3.2 provides the power curve of the engine configuration tested, the power as corrected to ISO 1585 ranged from 21 kW to 65.3 kW over the speed range tested.

These results along with other data collected is provided for review in Tables 5.3.1 and 5.3.2 below.



Graph 5.3.1 Full load torque and BMEP (ISO1585)



Graph 5.3.2 Full load power and torque (ISO1585)

Engine speed (rpm)	Torque (Nm ISO 1585)	Power (kW ISO 1585)	BMEP (kPa ISO 1585)	Exhaust Gas Temperature (°C)				Atmospheric Pressure (kPa)
				Cyl 1	Cyl 2	Cyl 3	Cyl 4	
1500	132.9	21.0	701.4	576	587	540	552	101.8
2000	143.8	30.2	758.9	595	610	569	576	101.8
2500	158.1	41.8	834.2	648	658	622	625	101.8
3000	174.2	54.9	919.3	694	700	684	677	101.8
3500	176.1	65.3	929.0	726	737	685	688	101.8

Table 5.3.1. Full load engine performance data

Engine speed (rpm)	Intake Air Temperature (°C)	Coolant Temperature (°C)	
		Cyl 1	Cyl 2
1500	32	80	80
2000	33	80	79
2500	32	78	78
3000	33	81	81
3500	34	80	80

Table 5.3.2. Full load engine performance data

6 CONCLUSIONS

Orbital successfully completed engine testing on the Revetec X4V2 engine, both at part and full load.

The part load BSFC ranged from 1568 to 212 g/kWh depending on the speed and load point tested.

The full load torque ranged from 132.9 to 176.1 Nm between 1500 and 3500 rpm.