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Highly Efficient Lubricant for Sport Motorcycle Application - Fuel Economy and Durability Testing

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ABSTRACT

As a result of extremely competitive market environment and severe emission legislation, motorcycle manufacturers are giving increased focus to the lubricant as a potential tool to improve engine performance reducing at same time tailpipe emissions and fuel consumption. However, due to very specific hardware constraints, application of highly efficient low viscosity oils to modern motorcycle requires careful formulation approach and thorough testing procedure. Previous work carried out by Castrol and described in SAE paper # 2011-32-0513 indicated that optimized, low viscosity motorcycle engine oils, formulated with dedicated technology to combine optimum clutch compatibility with engine and gearbox protection, can bring significant increase in engine power and acceleration in comparison with commercially available lubricants. This paper describes the progress of the development work, aiming at further understanding potential benefits and constraints arising from the application of low viscosity, highly efficient engine oils to current motorcycle engine technology. The work included the evaluation of the fuel economy potential for experimental low viscosity formulations using a sport tourer motorcycle fitted on chassis dynamometer, followed by extended high speed engine durability evaluation of one of the formulations on two different super sport motorcycle engines, representative of latest generation hardware technology. Results of Fuel Economy tests showed that carefully formulated low viscosity lubricants can provide reduction in fuel consumption when compared with conventional, commercially available products. Both the durability test programs were successfully completed with key engine and driveline components in good conditions at end of test, confirming potential applicability of low viscosity engine oils to modern high performance sport bikes.

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INTRODUCTION

Unlike passenger car where lubrication of engine and gearbox is separated and clutch is dry type, a typical sport motorcycle powertrain uses the same fluid to lubricate engine and gearbox and cool the clutch. The lubricant must therefore fulfill a number of different and often conflicting tasks. A good motorcycle lubricant must be able to protect key engine components from wear and deposits and to control evaporation through piston ringpack under the extreme speed, load and temperatures typical of sport operations. At the same time, oil must protect small and heavily loaded gears from wear, pitting and scuffing, as well as ensure the correct level of friction between clutch plates in order to allow their smooth engagement, prevent slip under high load and protect friction material from premature wear. Considering these fundamental performance criteria, it becomes clear that a motorcycle lubricant should be formulated to provide a thicker, more thermally and shear-stable oil film than a passenger car oil, and must have higher friction coefficient; for these reasons the application of low viscosity, low friction formulation technology for energy conserving purposes to motorcycle has been up to now a very challenging objective and, as a matter of fact, the majority of motorcycle models in the market is still serviced with conventional lubricants of relatively high viscosity (typically SAE10W-40 or above). However, due to continuous demand for increased engine responsiveness coupled with reduction of fuel consumption and tailpipe emissions, the application of low viscosity engine oils to motorcycles becomes more and more a desired step. Development of motorcycle-.specific energy conserving formulation technology, followed by extensive testing using representative bench motorcycle test is therefore required in order to ensure balance between efficiency and durability.

Table 1. n- Characteristics of Candidate and Reference Oils

Oil code	001B	002A	032A	041B	003A
Type	Candidate	Candidate	Candidate	Reference for durab.	Reference for FE
Viscosity Grade	0W-20	0W-30	5W-40	10W-40	15W-40
API Classification	SL	SL	SL	SL	SL
JASO T903 : 06 classification	MA2 type performance *	MA2	MA2	MA2	MA2
Additive type	A	A	A	A	A
Base oil type	Group IV	Group IV	Group III.	Group I/III	Group I
Kinematic Viscosity @ 100 °C, cSt	8.21	9.98	13.0	12.8	14.5
Kinematic Viscosity @ 40°C, cSt	41.98	54.96	77	83	103.6
Viscosity Index	175	172	170	150	136
HTHS Viscosity. cP	2.6	2.9	3.5	3.5	3.8
Noack evaporation, % wt	6	6	9	13	13
Phosphorus, % wt	0.096	0.096	0.096	0.096	0.096

Table 2. Summary of rolling road and bench tests

Performance Area	**Test type**	**Rig type / Engine / Bike type**	**Test Method**	**Measured parameter**
Fuel Consumption	Rolling Road	Sport Tourer 1300 cc, water cooled	Castrol in-house	Fuel Consumption (by Carbon Mass Balance)
Engine and driveline durability	Rolling Road	1000cc superbike, water cooled	Castrol in-house	Used oil analysis, engine/ driveline visual rating, piston deposit rating
	Bench	600cc supersport, water cooled	Castrol in-house	

EXPERIMENTAL FORMULATIONS

Two of the experimental lubricants described in SAE paper # 2011-32-0513 were used for this work. These are a SAE 0W-20 and a SAE 0W-30 formulation respectively, using fully synthetic base oils (Group IV), shear stable viscosity modifier and a motorcycle specific additive package. The additive system comprises metallic detergents, ashless dispersant, zinc - phosphorus anti-wear and a combination of ashless and metallic antioxidant. The additive system was formulated with reduced phosphorus level, with the objective of ensuring good catalyst compatibility.

A third formulation (SAE 5W40) blended with Group III base oils and same additive system of 001B and 002A was added to the test matrix in order to allow a more complete mapping of viscometric effect on fuel consumption. The experimental formulations were tested against reference oils meeting OEM requirement for each engine used for testing. In order to reduce number of variables and allow a better interpretation of test results, reference oils were formulated with same additive system of candidate oils. Details on candidates and reference oils are given in Table 1.

TEST PROGRAM

The Initial test program for clutch compatibility, power / acceleration and engine / gearbox durability carried out on 001B and 002A formulations has been summarized in SAE Paper # 2011-32-0513. For the work described in this paper, in-house rolling road Fuel Economy test method and bench and rolling road durability procedures were adopted. Table 2 contains a summary of the test performed. In combination with those previously performed, these tests give comprehensive overview of candidate performance across the performance spectrum of motorcycle engine oils

FUEL ECONOMY

Fuel Economy is one of the most challenging areas for motorcycle lubricant testing. Relatively limited differences typically given by candidate oils, along with high influence of large number of test parameters on fuel consumption trend across the experiment, can heavily affect test precision reducing discrimination between candidates and reference oil. High control of test conditions along with careful design of the experiment is therefore necessary in order to capture statistically meaningful differences. For this work, an in-house test procedure using a latest generation 4 in-line sport tourer motorcycle fitted on rolling road was developed. The drive cycle adopted is the World Harmonized Motorcycle Drive Cycle (WMTC), which is represented in figure No 1. The WMTC a highly transient cycle designed in order to represent real-life motorcycle running conditions. The cycle is 1800 seconds in total and it is divided in three 600 sec phases, representing stop and go, urban and extra urban riding respectively.

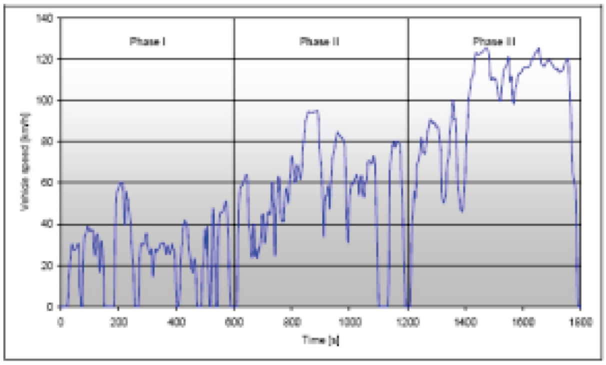


Figure 1. WMTC drive cycle

The test cycle consisted in 5 repeats of the WMTC per candidate (one cold start and 4 hot starts). Before each hot cycle, a 20 minutes constant speed engine stabilization phase was performed. For each candidate fuel consumption was measured for 1 cold start WMTC and for 3 separate hot starts (the first of the hot start cycles was a warm up and stabilization cycle and measurement was not taken). Each candidate oil run was followed by a reference run and the test matrix included three repeats for each candidate. For each single WMTC, exhaust gases were collected separately for the three stages using a bag sampling system and a CO/CO_2 gas analyzer. Fuel consumption was then calculated using Carbon Mass Balance Method. A snapshot of test cycle is given in Figure 2. Fuel Consumption data for each candidate

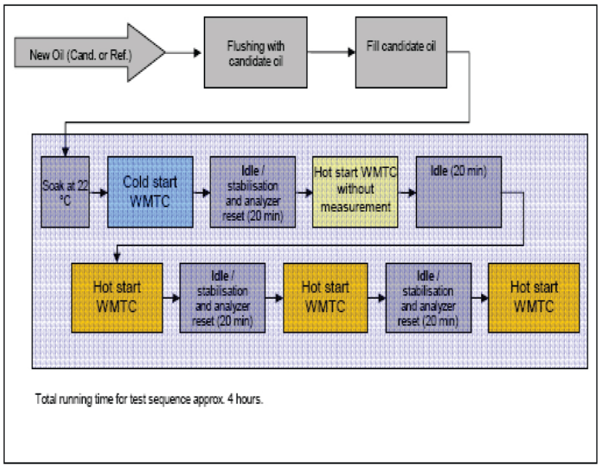


Figure 2. Test Cycle Snapshot

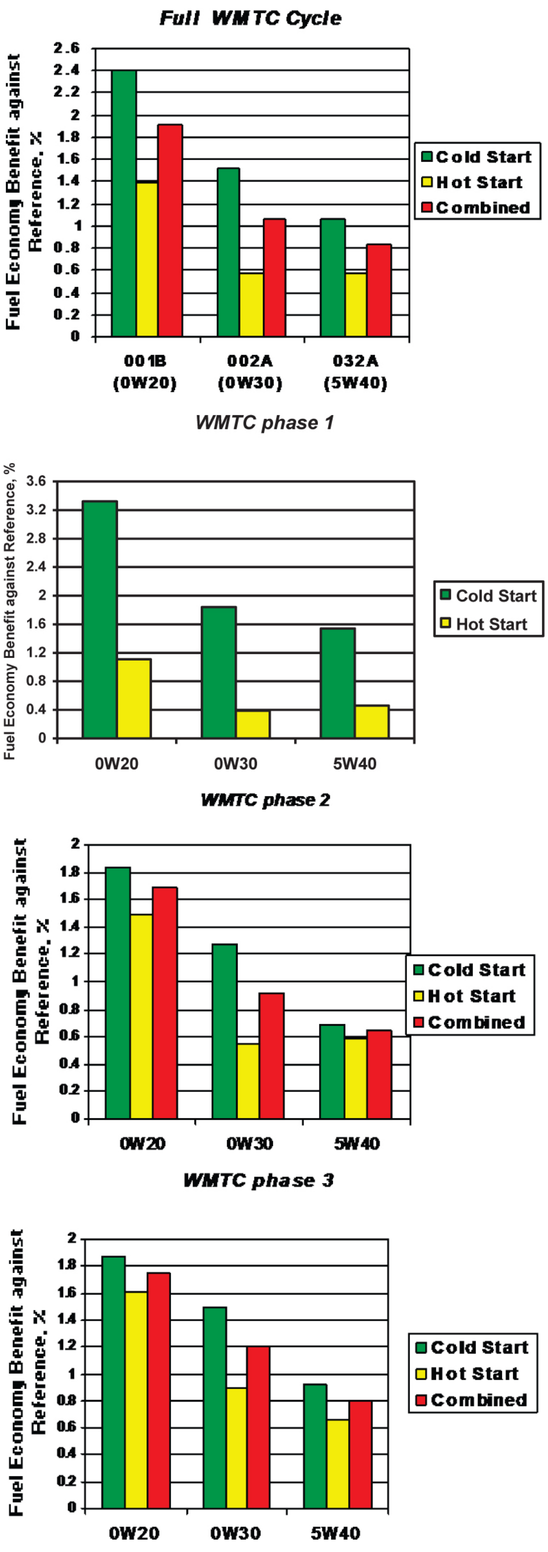


Figure 3. Fuel Economy Summary

were compared with nearest reference run and the results averaged for the three candidate runs. Figure 3 shows the summary of the Fuel Consumption measurements for cold, hot and combined cold + hot measurements, expressed as % candidate improvement versus SAE15W-40 reference oil (003B).

The test showed a certain level of variability with significant drift of the reference position. A"bracketing" referencing method allowed partial compensation of the reference drift and the LSD - Least Significant Difference - has to be considered good for this type of testing. Table 3 reports the Standard Deviation and LSD for the entire experiment. As expected, the 0W-20 oil gave the best results across all cycles, with a maximum FE benefit of 2.4% in the cold cycle, followed by the 0W-30 and 5W-40 respectively. In hot start, 0W-20 gave again the biggest difference whilst 0W-30 and 5W-40 gave comparable results

Table 3. Fuel Economy Results Statistical Evaluation

	Cold		Warm		Combined	
Oil code	Fuel Cons.	% change	Fuel Cons.	% change	Fuel Cons.	% change
E0888M/001B/01	**5.54**	**2.40%**	**5.26**	**1.39%**	**5.40**	**1.92%**
E0888M/002A/01	**5.59**	**1.52%**	5.30	0.57%	**5.44**	**1.07%**
E0404M/032A	**5.61**	**1.06%**	5.30	0.57%	**5.46**	**0.83%**
E0888M/003A/01	5.67		5.33		5.50	
SD	0.035	0.61%	0.030	0.57%	0.034	0.62%
LSD vs Reference	0.041	0.72%	0.036	0.67%	0.040	0.73%
LSD among Cand.	0.050	0.88%	0.044	0.82%	0.049	0.89%

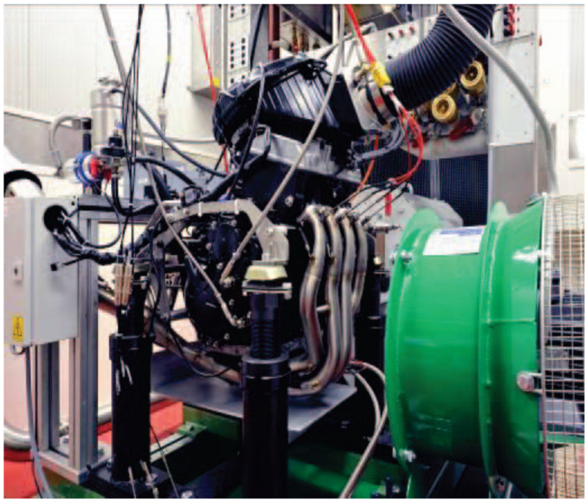
Results printed in bold are significantly different from the reference at the 90% confidence level.
Results bracketed together are not significantly different at the 90% confidence level.

DURABILITY

After consideration on supersport motorcycle hardware design, and relative potential limits to the application of ultra low viscosity oils, it was decided to start durability test program on the 0W-30 candidate. In SAE paper # 2011-32-0513, durability results for a 30.000 Km high speed track teston 0W-30 candidate oil 002A were reported, indicating the potential suitability of this oil on the specific hardware used. Therefore, additional testing on 0W-30 could have given more complete understanding of the tolerance of typical high performance motorcycle engines to low viscosity oils, allowing at same time to understand the possibility to stretch application to more extreme viscosity profiles such as 0W-20. In order to complete the assessment of durability impact of candidate oil on a wider range of motorcycle models and riding conditions, two different evaluation procedures were used; a 100 hrs "track lap" bench simulation using a four in line 600 cc super sport engine and a 30,000 Km high speed chassis dyno test on a 1000 cc "superbike" model of latest generation. These two tests were designed in order to evaluate the impact of the low viscosity candidate on engine and driveline durability under high speed / racing riding conditions over extended period. Both tests were run under highly controlled conditions, allowing a precise comparison with data obtained on reference oils.

Bench durability test

This test is part of the Castrol in-house test evaluation procedure for motorcycle engine oils. Installation is shown on Picture 1. Engine is fitted on a fully transient A/C dynamometer controlled by software, and test cycle consists in a track lap simulation with data from World Supersport Championship telemetry (Brands Hatch circuit) followed by a steady state, high speed high load section. Each cycle is looped continuously for a total length of 100 hours with no oil change. Every 10 hours the test is paused for used oil sampling and leveling with fresh oil. Key parameters controlled include oil sump and gallery temperature, oil pressure, coolant in and out temperature, fuel temperature, air intake temperature, exhaust gas temperature and lambda.



Picture 1. Supersport Durability Installation

After break-in, a full power curve is performed to check engine performance of overlaid with that of start of test on order to check eventual drop in performance new engine. At end of test, the same power curve is performed and. At end of test, engine is stripped and key components visually rated for wear, with rating assigned on a 1 (Excellent) to 5 (Unsatisfactory) scale. Gear Pitting is assessed by area measurement and expressed as % of pitted area versus total gear teeth surface. Piston deposits are rated according to DIN 51-361-02-VB method where 100 = completely clean piston and 0 = completely dirty. Two tests were run for this work, one on candidate oil 002A and one on reference oil 041B, a SAE 10W-40 formulation conform to OEM service fill recommendation. Both tests were completed successfully with all parameters under control during test and without engine problems being reported. Figure 4 shows power curve at SOT and EOT for candidate and reference runs respectively. Used Oil Analysis on samples take at 10 hrs interval were performed and results reported in charts 5 and 6. End of test component wear evaluation is summarized on Table 4. Gear box pitting and piston cleanliness rating evaluation for both bench and chassis dyno tests are summarized in Table 6 and 7 respectively.

Table 4. Engine Component Rating from Bench Durability Test

OIL	**E0888M/002A (Candidate)**		**E0698M/041B (Reference)**	
PART	**COMMENT**	**RATING**	**COMMENT**	**RATING**
Crankshaft				
Main journals	Polished, run marks, trace wear	3	Polished, run marks, trace wear	3
Big end journals	Polished, run marks, # 4 trace scoring	3	Polished, run marks, # 4 trace scoring	3
Main bearings	TOP - Small polished area on No1 only 2 Bottom - All with large polished areas, light cavitation on all	2 3	Top- polished area on No5 only 2 Bottom- Large polished patches with trace to light cavitation	2 3
Big End Bearings	TOP - Large polished patches(75%) small areas through next layer Bottom - Polished areas, small patches of first layer gone	4 4	Top- Large polished patches(75%) with areas of first layer bearing gone Bottom- Polished patches, cavitation evident small patches of first layer gone	4 4
Small End Bearings	Traces of light brown lacquer	3	Some light brown lacquer, excellent condition, trace light brown on outside of rod eyes	2
Gudgeon Pins	All, pins are covered in fine scuffings over most of the entire gudgeon pin	3	All the same, i.e. con rod area covered in very fine scoring with traces of light scoring in piston bearing areas	3
Average		2.8		2.8
Camshaft				
Inlet lobes	Heavy polish, trace wear, grey patches on noses, actually the patches are "fine pittings" rather like gearbox micro pitting	2	All with heavy polish & trace wear, looked at with mag glass, slight rippling of polish surface on noses & ramps. A grey area on all noses	4
Exhaust lobes	Heavy polish, trace wear, grey patches on noses, actually the patches are "fine pittings" rather like gearbox micro pitting	4	Similar to inlet, grey patches more pronounced, some pin prick sized pits can be seen using magnified glass	4
Cam journals	Similar to inlet, Heavy polish, trace wear, pitting.	3.5	All journals with trace to light scoring	4
Cap bearings	Light scoring on most journals	3.5	All with light scoring & heavy run marks	3
Head bearings	Light to medium scoring on most bearings	4	All good except No1 with some light scoring	3
Bucklets inlet	All in good order	2	All with trace ringing, most with annular chatter marks, trace wear	3
Bucklet exhaust	Heavy polish, most with annular scuff marks	4	No5 poor rotation, trace wear & ringing, some with chatter marks	4
Cam chain	Not re-usable - tight spots	4	Some tight spots, general appearance just serviceable	4
Tensioners	Medium to heavy wear	4	Medium wear	4
Average		3.6		3.4
Cylinder bore	Trace scoring only	1.5	Bores in exceptionally good condition, almost free of any minor 2scoring or lacquer	1.5
Clutch assy				
Basket	Medium wear on drive lugs	3	Medium wear on drive lugs	3
Hub	Light wear on drive splines	2.5	Light wear on drive splines	3
Friction Plates	No distress, medium wear on drive ears	3	No distress, medium wear on drive ears	3
Steel Plates	No distress, trace wear on drive ears	1.5	No distress, trace wear on drive ears	2
Average		2.5		2.5

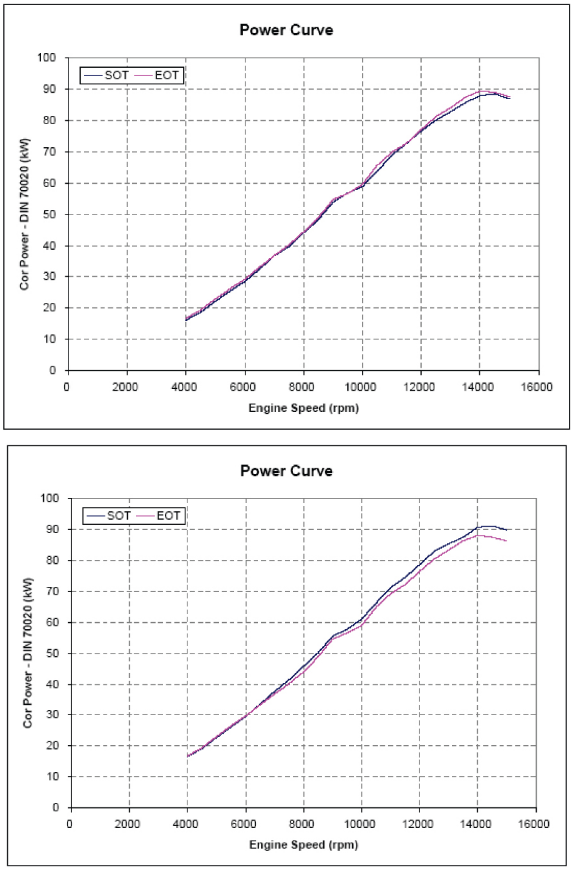


Figure 4. Power at SOT and EOT for Candidate 002A (top) and Reference 041B (bottom)

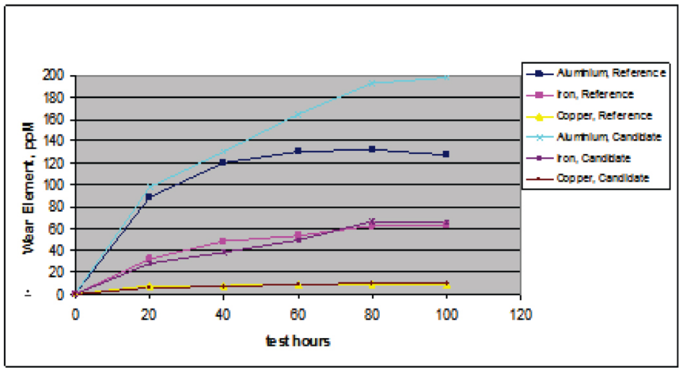


Figure 5. Bench Durability Used Oil Analysis

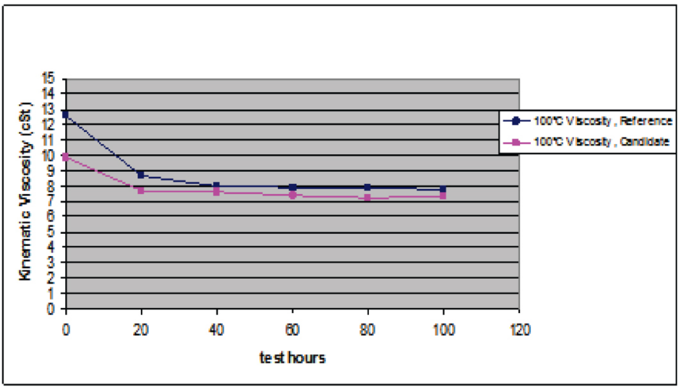
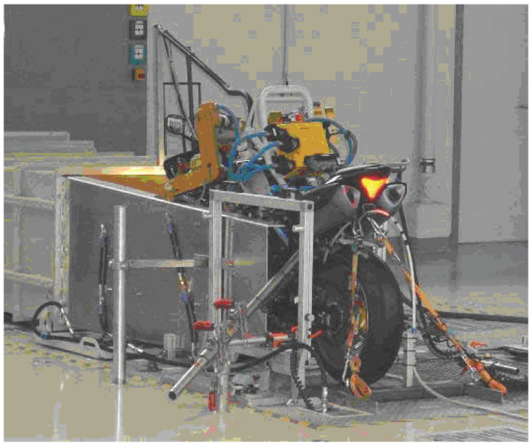


Figure 6. Bench Durability Used Oil Analysis

Chassis dyno durability test

A model year 2011, 1000 cc superbike was used for this test. The motorcycle was fitted on chassis dyno ridden by computer controlled autopilot. Picture 2 shows the bike on the dyno and equipped with the robot-rider. The test cycle, represented in figure 7, consisted of a series of accelerations and decelerations in 4th, 5th and 6th gear up to a speed of 241 Km/h, with an average speed of 173 Km/h. Total cycle length was 2700 sec, corresponding to 129.7 Km. The cycle was looped continuously for a total length of 30.000 Km. The test was paused every 2000 Km for oil sampling and leveling and oil was drained and changed every 10,000 Km according to manufacturer recommendation. Key parameters controlled included oil sump and gallery temperature, oil pressure, coolant in and out temperature. After break-in, a full power curve was performed to check engine performance of new engine. At end of test, the same power curve was performed and overlaid with that of start of test in order to check eventual drop in performance. Two tests were run for this work, one on candidate oil 002A and one.



Picture 2. Chassis Dyno Superbike Installation

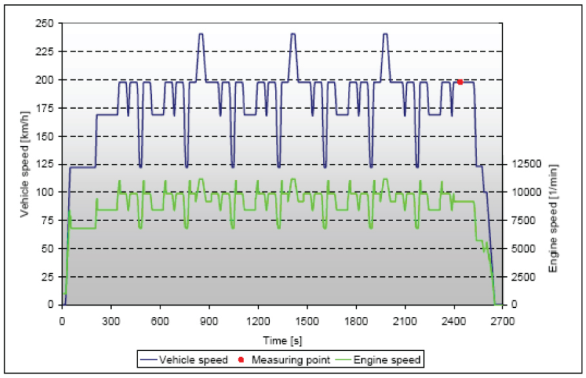


Figure 7. Chassis Dyno Drive Cycle

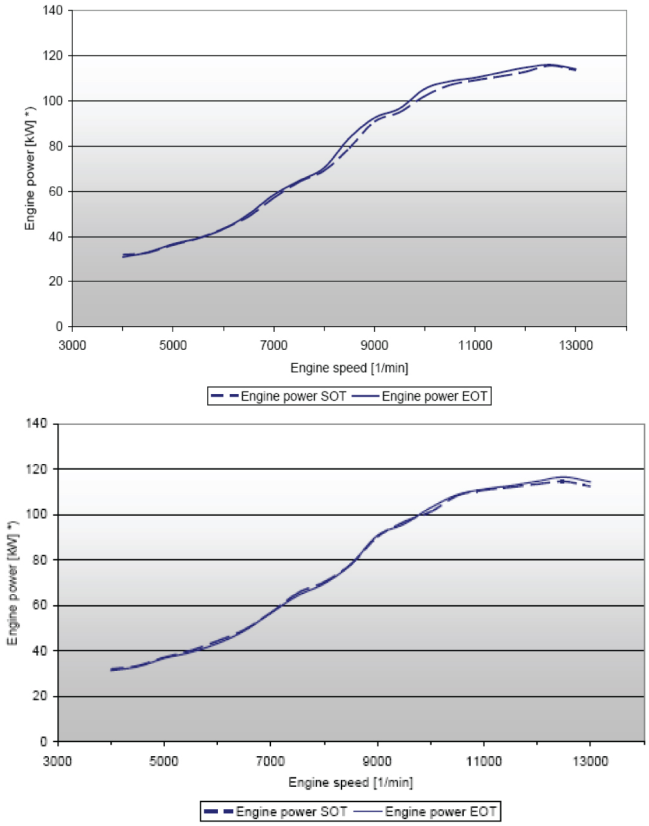


Figure 8. Power at SOT and EOT for Candidate 002A (top) and Reference 041B (bottom)

Two tests were run for this work, one on candidate oil 002A and one on reference oil 041B, which conforms to the OEM service fill recommendation. Both tests were completed successfully with all parameters under control during test and without engine problems being reported. Figure 8 shows power curves at SOT and EOT for the candidate and reference run. Both the candidate and reference tests were completed successfully with no engine problems being reported. Used Oil Analysis (wear elements and viscosity) are reported in charts 9 and 10, whilst chart number 11 reports the oil top-ups for candidate and reference. Engine rating results are summarized in table 5, gearbox pitting measurement in table 6 and piston cleanliness rating in table 7.

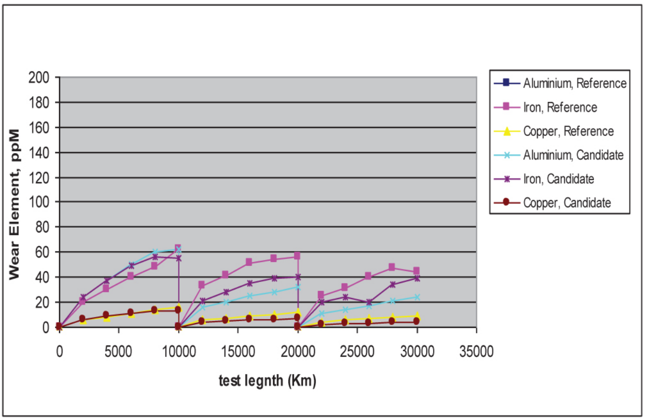


Figure 9. Chassis Dyno Durability Used Oil Analysis

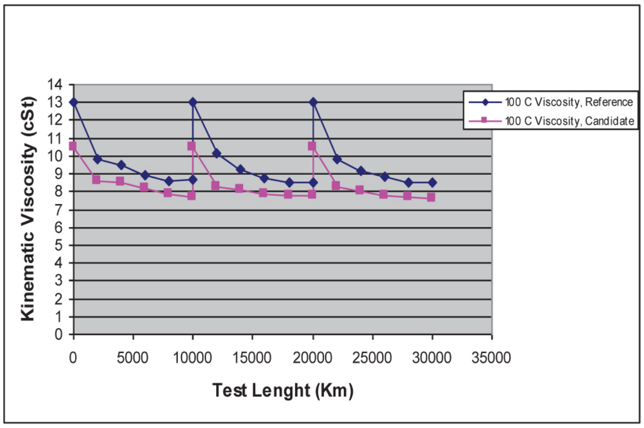


Figure 10. Chassis Dyno Durability Used Oil Analysis

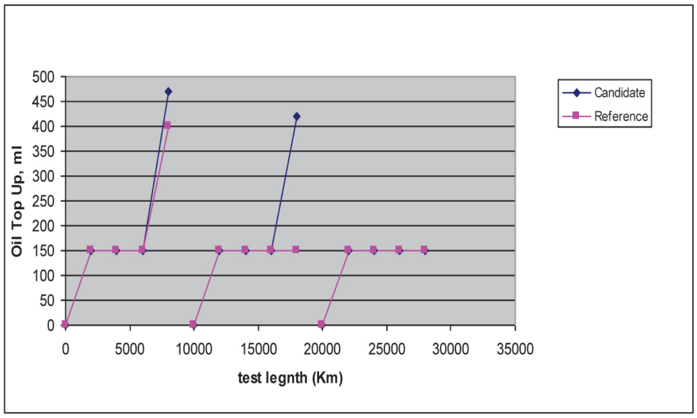


Figure 11. Chassis Dyno Durability Oil Consumption

Table 7. Piston Cleanliness Rating for Durability Tests

	Bench		**Chassis Dyno**	
Piston	**Candidate**	**Reference**	**Candidate**	**Reference**
1	78	91	63	69
2	81	93	78	89
3	83	90	74	86
4	80	94	65	81
Average	81	92	70	81

Durability test - summary of results

Both the durability test programs were completed successfully by the candidate and reference oil. The end of test power for candidate and reference was equivalent to that of new engine in both the bench and the chassis dyno tests. used oil analysis from bench test shows comparable level of iron and copper for candidate and reference, but a high level of aluminum for candidate (however, engine inspection revealed that there was no areas showing significantly higher wear in comparison with reference oil). in chassis dyno test, wear elements accumulation throughout test followed equivalent trend for reference and candidate. component

Table 5. Engine Component Rating from Chassis Dyno Durability Test

OIL	**E0888M/002A (Candidate)**		**E0698M/041B (Reference)**	
PART	**COMMENT**	**RATING**	**COMMENT**	**RATING**
Crankshaft				
Main journals	Light to medium polished areas, some fine scratches, several wear marks	2.5	Light polished areas, some fine scratches, several wear marks	2
Big end journals	Light to medium polished areas, some fine scratches, several wear marks	2.5	Light polished areas, some fine scratches, several wear marks	2
Main bearings	Light to medium polished areas, light to medium scratches	3.5	Medium polished surfaces through first layer with some small stressed areas	3
Big End Bearings	Large polished areas, small and medium patches of material break-outs	4.5	Large polished areas, small patches of material break-outs	3.5
Small End Bearings	Light coloured and light polished surface on thrust sides	2.5	Light coloured and light polished surface on thrust sides	2.5
Gudgeon Pins	Large polished areas, light scratches, light tangible wear	3.5	Large polished areas, light scratches, light tangible wear	3.5
Average		3.2		2.8
Camshaft				
Inlet lobes	Polished areas, light to medium wear, scratches, formation of micro pitting at tip	3.5	Polished areas, light to medium wear, scratches, formation of micro pitting at tip	4
Exhaust lobes	Polished areas, light to medium wear, scratches, formation of micro pitting at tip	3	Polished areas, light to medium wear, scratches, formation of micro pitting at tip	4
Cam journals	Light polished areas, light scratches	3	Light polished running-in wear, light scratches, most of original surface is visible	2
Cap bearings	L Light polished areas, light scratches	2.5	Light polished running-in wear, light scratches, most of original surface is visible	2
Head bearings	Light running-in polishing, nearly no wear	1.5	Light running-in polishing, nearly no wear	1.5
Bucklets inlet	No wear visible	1	No wear visible	1
Bucklet exhaust	Light running-in polishing, nearly no wear	1.5	Light running-in polishing, nearly no wear	1.5
Cam chain	Light wear grooves at root of tooth segments are visible	2.5	Light wear grooves at root of tooth segments are visible	2.5
Tensioners	Light to medium wear	2.5	Light to medium wear	3
Average		2.4		2.4
Cylinder bore	Nearly nor wear, all honing marks are still visible, light to medium scratches	2.0		2.0
Clutch assembly				
Basket	Light wear on drive pillars	2.5	Light wear on drive lugs	2
Hub	Light to medium wear on drive splines	3	Light to medium wear on drive splines	2.5
Friction Plates	Light discoloration at outer disc light wear on drive ears	2.5	Light discoloration at outer disc light wear on drive ears	2.5
Steel Plates	Traces of wear on drive ears, no discoloration, no wear at friction surface	2	No distress, trace wear on drive ears	2
Average		2.5		2.4

evaluation from bench test showed a significant level of wear on big end bearings, with level of material removal equivalent for candidate and reference; the valvetrain was also significantly worn on both engines, with cam lobes showing large patches of polishing and pitting, and cam chain at end of its useful life; this is however expected considering that this test is extremely severe with engine revving continuously up to maximum speed under full load. the wear rating for the chassis dyno test was also comparable for the two oils, although the candidate showed larger patches of material removed from big end bearings. the end of test gearbox conditions for candidate and reference in the two tests were good with only micro-pitting being observed and virtual absence of macro-pitting. piston cleanliness at the end

Table 6. Gear Pitting % Rating for Durability Tests

	Rolling road test				**Bench test**			
Gear #	**candidate**		**reference**		**candidate**		**reference**	
	micro	macro	micro	macro	micro	macro	micro	macro
6° main	33,6	0	35	0	13	0	25	0
5° main	47	0	40	0				
4° main	17,6	0	0,5	0				
6°counter	4,1	0	10	0	47,2	0	55	0,2
5°counter	8,8	0	11,1	0				
4°counter	0,7	0	1	0				

of the two tests was very high for both oils, with the reference scoring slightly better than the candidate. oil consumption, a critical parameter when considering potential application of low viscosity oil as service fill, was about 15% higher for candidate than reference oils when measured during the chassis dyno test; this has to be considered a good result bearing in mind the significant difference in viscosity between the two oils. overall, the candidate oil showed equivalent wear protection

SUMMARY/CONCLUSIONS

The work confirmed that evaluation of lubricant contribution to Fuel Economy in motorcycle is an extremely challenging objective. The experiment showed a statistical Fuel Economy benefit of up to 2.4% for extreme viscosity profile (SAE 0W-20) in comparison with 15W-40 reference oil. Relatively low responsiveness of the specific hardware chosen, along with intrinsic variability of fuel consumption measurement did not allow to confirm in full the FE potential of higher viscosity candidates. However, a directional benefit in fuel economy could be identified also for 0W-30 oil, which in previous experiments has shown to be capable to deliver tangible increase in power output in comparison with different benchmark products. The same candidate oil was extensively tested for durability on three different engines, and it showed to be capable of providing level of engine and driveline protection comparable to that of conventional engine oils used as reference. Data from this work therefore indicate that application of ultra-low viscosity engine oils to modern sport motorcycle hardware is one the possible ways forward to improve performance whilst contributing to the reduction of greenhouse gases emission. Further evaluation of Fuel Economy potential, along with assessment of impact on hardware durability of more extreme formulation profile is necessary in order to exploit in full the potential for this approach.

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CONTACT INFORMATION

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