

Testing Shift Points for Optimal Acceleration

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Recently, it has come to my attention that due to the broad torque curve of the 2.3L MZR engine, as well as the sudden drop in power after 5500 rpm, that shifting at 4500 would be a better procedure for the MZR power band. After testing, it was determined that shifting at 5500 rpm was a much better decision, in terms of vehicle speed, and in terms of acceleration times.

INTRODUCTION

In order to test for the optimal shift point between two RPMs, a physical test was in order. The equipment used was a 2006 Mazdaspeed6. The vehicle in question did not contain the Mazda issued ECU Reflash. Also present on the test vehicle was a Fujita Cold Air Intake, a homemade intercooler sprayer, and cp-e Engine Mount. The StreetUnit Test Pipe was removed two weeks ago, and replaced with the standard catalytic converter. The car has been driven over 500 miles since the last modification, and/or oil change, and the ECU Learning Routine is not present. On the day of the test, the temperature was 51 Degrees Fahrenheit, barometric pressure was 28.95 inches and rising, and humidity was at 41%. Testing conditions were optimal.

The circuit used was an aircraft taxiway, devoid of any traffic, flat, and clean. The measuring equipment was a Casio Stopwatch, operated by an impartial passenger. No vehicle modifications between runs were performed.

The procedure for testing was very straightforward. There was to be two tests, a timed acceleration test, as well as a timed distance test. For each test, two runs were performed at the required RPM shift point, and direction was travel was reversed for the second run. The reversal of direction allows for compensation of wind effects, elevation changes and road imperfections.

PROCEDURE AND DISCUSSION

The first acceleration test called for a 20 mph to 75 mph WOT test, shifting at 4500 rpm. Immediately upon completion of the test, the time was recorded, the intercooler was sprayed with a quick burst of water, and then the car was driven at 50 mph for a mile to help promote proper airflow to the intercooler. The car was then coasted back down to 20 mph, where the car was again placed under WOT, shifting at 5500 rpm to 75 mph. The time was recorded, intercooler sprayed, cool down mile driven. The car then reversed direction, and repeated the same test in

reverse order. The data collected is located in Table 1. It must be noted that Run #1-a involved running out 4th gear to 4800 rpm, whereas run 1-b included a shift right at 4500 rpm.

One might argue that by starting at 20 mph in second gear will yield a lot of turbo lag. Well, that is true, however, this turbo lag does not alter either shift point because this turbo lag is the same for both tests, and can be cancelled out. Even with turbo lag, the inconsistencies are still less than that of doing a "launch" from a dead stop.

Acceleration Test (20 mph - 75 mph)		
Lower time = Better Value		
Run #	Time (sec)	Avg Time
1-a	9.18	9.47
1-b	9.76	
2-a	8.78	8.7
2-b	8.62	
	Percent Difference:	8.85%
Run 1 denotes shifting at 4500 rpm		
Run 2 denotes shifting at 5500 rpm		
Two runs of each variant were performed, one in each direction to correct for wind, elevation changes and road imperfections.		
Ambient temperature at time of test: 51 degrees F.		
Between runs, and before a cool-down of one-mile easy driving, water was sprayed onto intercooler via homemade intercooler sprayer to dissipate, and aid in rapid evacuation of built up heat.		

Table 1. Acceleration Test.

As can be seen from the data, the average time for acceleration to 75 mph was 8.85% faster while shifting at 5500 rpm, than shifting at 4500 rpm. This 8.85% accounts for roughly .75 second difference between the two.

The second test, the Covered Distance Test tested the time, and final speed of the vehicle through one-tenth mile elapsed distance. The vehicle started at 5 mph, then under WOT completed one-tenth of a mile. The speed and time were recorded. The vehicle started at 5 mph to cancel any irregularities between runs in terms of launching (i.e., too much gas, too little gas, too much clutch slip, engine bog, heat soak effects, etc). The vehicle first performed the 4500 RPM shift point, then a cool down consisting of an intercooler

spray, and one mile cool down. Then the 5500 RPM shift point was tested, after which time, the vehicle direction was reversed, and the testing procedure was reversed. The data collected is located in Table 2.

Covered Distance Test (.1 mile)				
Run #	Time (sec)	Speed (mph)	Avg. Time (sec)	Avg. Speed (mph)
1-a	9.68	66	9.63	66.5
1-b	9.58	67		
2-a	9.18	70	9.15	70
2-b	9.12	70		
		Percent Difference:	5.24%	5.00%
Run 1 denotes shifting at 4500 rpm				
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Two runs of each variant were performed, one in each direction to correct for wind, elevation changes and road imperfections.				
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Table 2. Covered Distance Test.

As can be seen from the data, again, shifting at 5500 rpm showed a 5% increase in speed, as well as a 5.24% decrease in time. The data shows that neither direction showed a marked difference in time or speed, but that a greater difference was observed between shift points.

The above physical data could very well be explained using mathematics. Racers know that in order to achieve maximum acceleration out of an engine, that they need to create an engine with a very broad torque curve, but also, they need to maximize the area under the horsepower curve. Using the cp-e dyno charts for their X-Cel cold air intake as a reference, as well as a spreadsheet made using Microsoft Excel, and imputing in RPM's, gear ratios and axle ratios, it was determined that shifting at 5500 rpm allotted more area under the horsepower curve.

Gear Ratio	2750	3000	3250	3500	3750	4000	4250	4500
3.538	14.4	15.7	17.1	18.4	19.7	21.0	22.3	23.6
2.238	22.8	24.9	27.0	29.0	31.1	33.2	35.3	37.3
1.535	33.3	36.3	39.3	42.4	45.4	48.4	51.4	54.5
1.171	43.6	47.6	51.6	55.5	59.5	63.4	67.4	71.4
1.085	55.4	60.4	65.5	70.5	75.5	80.6	85.6	90.6
0.853	70.4	76.8	83.3	89.7	96.1	102.5	108.9	115.3

It can be seen that if one were to shift from first gear at 4500 rpm, then they would fall into second gear at 3000 rpm. This process seems to be very similar throughout gears 1, 2 and 3. From the horsepower curve, the slop of the line from 3000 rpm to 4500 rpm is:

$$.0427x + 100$$

When the horsepower curve is integrated from 3000 rpm to 4500 rpm, it can be seen that:

$$\int_{3000}^{4000} \frac{.0427}{2} x^2 + 100x$$

From 3000 rpm to 4500 rpm yields 390187 energy units.

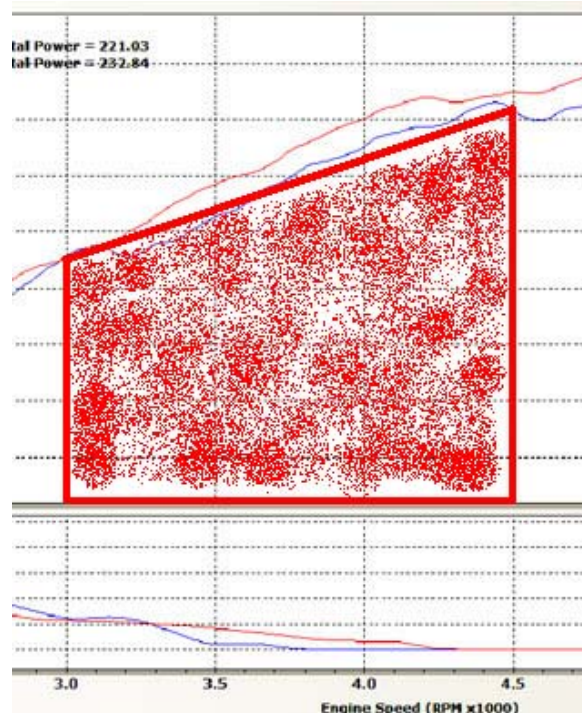


Figure 1. Integral of 3000 rpm to 4500 rpm.

Now, using the same principles, and using a shift speed of 5500 rpm, the following chart can be used to determine the new engine speed in the higher gear:

Gear									
Ratio	3500	3750	4000	4250	4500	4750	5000	5250	5500
3.538	18.4	19.7	21.0	22.3	23.6	24.9	26.2	27.6	28.9
2.238	29.0	31.1	33.2	35.3	37.3	39.4	41.5	43.6	45.6
1.535	42.4	45.4	48.4	51.4	54.5	57.5	60.5	63.5	66.6
1.171	55.5	59.5	63.4	67.4	71.4	75.3	79.3	83.3	87.2
1.085	70.5	75.5	80.6	85.6	90.6	95.7	100.7	105.7	110.8

The slope of the horsepower line is:

$$.00325x+115$$

and by integrating this equation:

$$\int_{3500}^{5500} \frac{.00325}{2} x^2 + 115x$$

yields 522500 energy units. It should be noted that this is a very approximate figure, and very crude equation, and it infact yields on the side of caution. The actual integral should be more than this number, but for the sake of argument, and to err on the side of caution, I will use this number for future calculations.

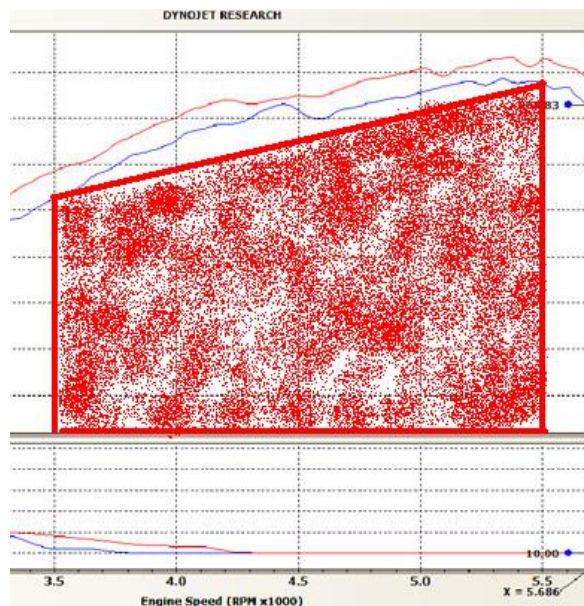


Figure 2. Integral of 3500 rpm – 5500 rpm

To determine the difference in power output, one must subtract the 4500-rpm integral from the 5500-rpm integral, and one will see that by shifting at 5500 rpm yields about 132,000 extra power units (actually it is more, but we used a low figure for sake of comparison). This is an 30% increase in power.

CONCLUSION

It can be seen that shifting at 5500 rpm will consistently prove to be a better alternative than shifting at 4500 rpm for multiple reasons. This higher shift point results

in faster acceleration times, higher trap speeds, as well as more usable power. Errors could have been due to using a stopwatch, reaction to start/stop times, speedometer inaccuracy, speedometer parallax, and/or speedometer time delay. The reaction time to start/stop the stopwatch is a consistent error as the same stop watch, and the same operator was used, so this error is null. Speedometer parallax is null because the operator was sitting in the same seat, and at the same angle for all runs. Speedometer inaccuracy would have been constant across all runs.

The physical data, and mathematical data all conclude that shifting at 5500 rpm is the better choice.

For future reviews, more sophisticated equipment should be utilized, and more shift points analyzed. Using cp-e's Standback would greatly help as it could record speed per unit of time, and this data could be derived into an acceleration graph. Once acceleration data is obtained for each gear, further analysis could show where rate of acceleration in one gear falls below the rate of acceleration in the next higher gear. This point would then become the new shift point.

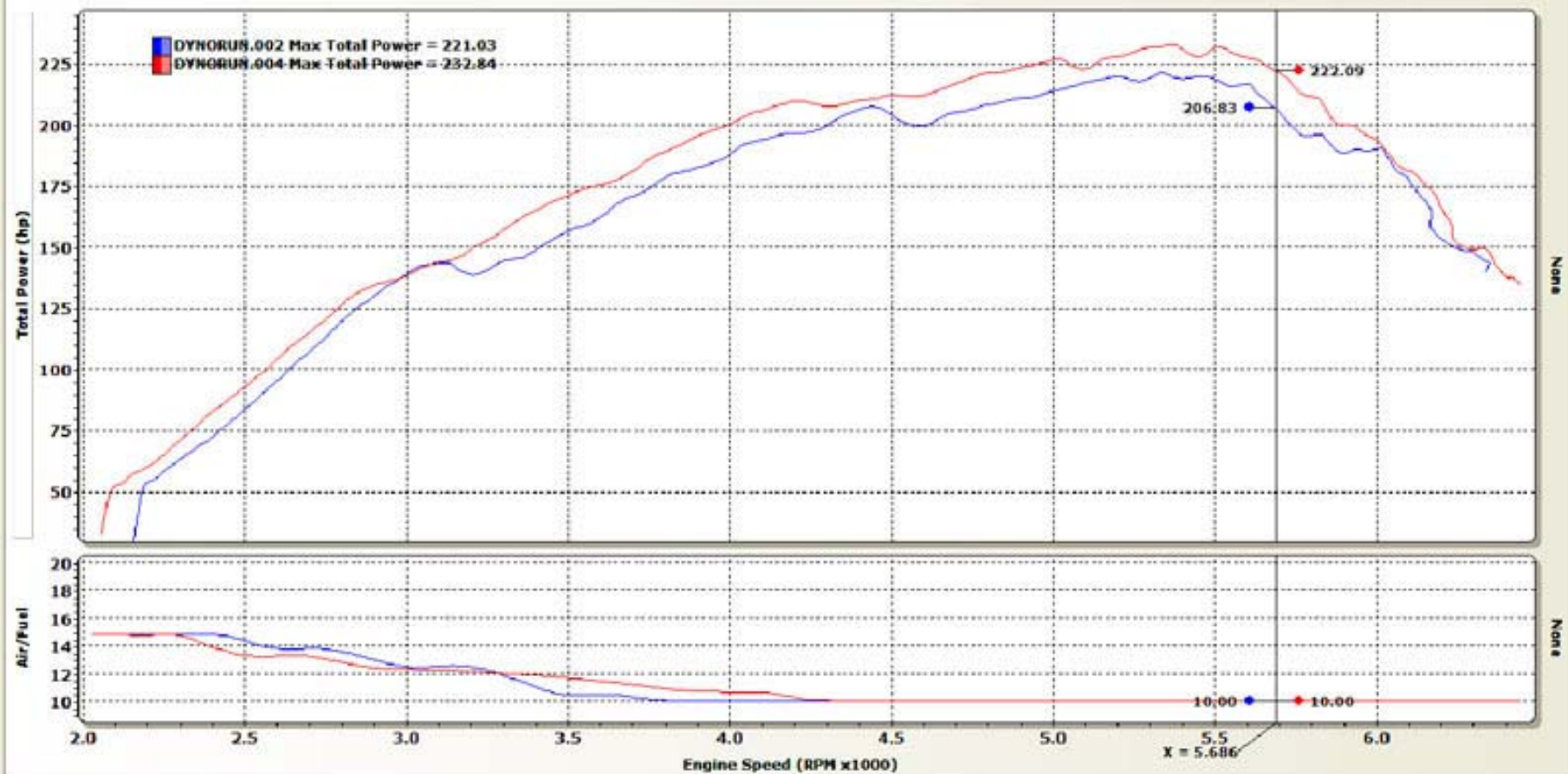
Speed at a given RPM																											
Axle Ratio	Gear Ratio		1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250	4500	4750	5000	5250	5500	5750	6000	6250	6500	6750	
3.941	3.538	13.94	5.5	6.8	7.9	9.2	10.5	11.8	13.1	14.4	15.7	17.1	18.4	19.7	21.0	22.3	23.6	24.9	26.2	27.6	28.9	30.2	31.5	32.8	34.1	35.4	
3.941	2.238	8.82	8.6	10.8	12.4	14.5	16.6	18.7	20.7	22.8	24.9	27.0	29.0	31.1	33.2	35.3	37.3	39.4	41.5	43.6	45.6	47.7	49.8	51.9	53.9	56.0	
3.941	1.535	6.05	12.6	15.7	18.2	21.2	24.2	27.2	30.3	33.3	36.3	39.3	42.4	45.4	48.4	51.4	54.5	57.5	60.5	63.5	66.6	69.6	72.6	75.6	78.7	81.7	
3.941	1.171	4.61	16.5	20.6	23.8	27.8	31.7	35.7	39.7	43.6	47.6	51.6	55.5	59.5	63.4	67.4	71.4	75.3	79.3	83.3	87.2	91.2	95.2	99.1	103.1	107.1	
3.350	1.085	3.63	21.0	26.2	30.2	35.2	40.3	45.3	50.3	55.4	60.4	65.5	70.5	75.5	80.6	85.6	90.6	95.7	100.7	105.7	110.8	115.8	120.8	125.9	130.9	135.9	
3.350	0.853	2.86	26.7	33.3	38.4	44.8	51.2	57.6	64.0	70.4	76.8	83.3	89.7	96.1	102.5	108.9	115.3	121.7	128.1	134.5	140.9	147.3	153.7	160.1	166.5	172.9	
RPM at a given Speed																											
		10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	
3.941	3.538	1904.8	2857.2	3809.6	4762.0	5714.5	6666.9	7619.3	8571.7	9524.1	10476.5	11428.9	12381.3	13333.7	14286.1	15238.5	16190.9	17143.4	18095.8	19048.2	20000.6	20953.0	21905.4	22857.8	23810.2	24762.6	
3.941	2.238	1204.9	1807.4	2409.8	3012.3	3614.7	4217.2	4819.6	5422.1	6024.6	6627.0	7229.5	7831.9	8434.4	9036.8	9639.3	10241.8	10844.2	11446.7	12049.1	12651.6	13254.0	13856.5	14458.9	15061.4	15663.9	
3.941	1.535	826.4	1239.6	1652.9	2066.1	2479.3	2892.5	3305.7	3718.9	4132.1	4545.3	4958.6	5371.8	5785.0	6198.2	6611.4	7024.6	7437.8	7851.0	8264.3	8677.5	9090.7	9503.9	9917.1	10330.3	10743.5	
3.941	1.171	630.5	945.7	1260.9	1576.1	1891.4	2206.6	2521.8	2837.0	3152.3	3467.5	3782.7	4097.9	4413.2	4728.4	5043.6	5358.8	5674.1	5989.3	6304.5	6619.7	6935.0	7250.2	7565.4	7880.7	8195.9	
3.350	1.085	496.6	744.8	993.1	1241.4	1489.7	1737.9	1986.2	2234.5	2482.8	2731.0	2979.3	3227.6	3475.9	3724.1	3972.4	4220.7	4469.0	4717.2	4965.5	5213.8	5462.1	5710.3	5958.6	6206.9	6455.2	
3.350	0.853	390.4	585.6	780.8	975.9	1171.1	1366.3	1561.5	1756.7	1951.9	2147.1	2342.3	2537.4	2732.6	2927.8	3123.0	3318.2	3513.4	3708.6	3903.8	4098.9	4294.1	4489.3	4684.5	4879.7	5074.9	

File Tools Help

Correction Factor: SAE Smoothing: 5

DYNOJET RESEARCH

CF: SAE Smoothing: 5



Covered Distance Test (.1 mile)				
Started at 5 mph, 1st gear, clutch fully engaged so as not to add uncertainty from launching				
Run #	Time (sec)	Speed (mph)	Avg. Time (sec)	Avg. Speed (mph)
1-a	9.68	66	9.63	66.5
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