Draft

Development of the Light Load UDDS and CARB Heavy Heavy-Duty Diesel Truck Engine Dynamometer Test Cycles

Collection of Data on Engine Operating Parameters

The light load UDDS and the heavily loaded CARB heavy heavy-duty diesel truck (HHDDT) cruise cycles were both developed from engine operating parameters. The engine operating parameters were obtained from operating the test vehicle with specific engine installed on a chassis dynamometer while recording the J1939 signal from the engine ECM. This allowed the development on an engine dynamometer test cycle that had a direct correspondence to the loads the engine would experience where operated on a chassis dynamometer.

The 2006, 11 liter Cummins ISM was equipped in an International truck chassis. This truck had an empty weight of 13,200 lbs. and a fully loaded capacity of 66,000 lbs.

The chassis dynamometer test cycles were run at CARB's Heavy-Duty Vehicle Emissions Testing Laboratory in Los Angeles, CA. The vehicle was operated over the UDDS and CARB HHDDT cruise cycles while the J1939 signal was collected to obtained the engine parameters. The "light" UDDS was run with the truck loaded to its empty weight, without a trailer. For the CARB HHDDT cruise cycle, the truck was loaded on the dynamometer to its fully loaded capacity.

A total of at least 7 iterations were performed for each test cycle to obtain a sufficiently robust data set for the development of the engine dynamometer test cycles. During each test run, regulated and standard gas phase data were collected including NMHC, CO, NO_x, and CO_2.

Initial Development of the Engine Dynamometer Test Cycles

The engine dynamometer cycles were developed from the engine speed and torque values from the J1939 data stream. Initially, the engine speed and torque were averaged over all of the test iterations. It was found that slight differences in time alignment between different test iterations resulted in differences in the exact location of the peaks in torque and engine speed. Specifically, the engine parameters were be near a peak in load for one cycle, while the loads for other test cycles would be lower at the same point. As such, the peaks in engine speed and torque could not be adequately represented with a cycle based solely on averaging.

It was decided instead to utilize a single test iteration that was determined to be most representative of the test run series on each cycle. Three main criteria were used in selecting the most representative set of engine parameters for the cycle development.

--- NO_x emissions for the engine parameter data set compared with the average value.
--- The sum of squares difference between the actual recorded velocity and the true speed trace
--- CO_2 emissions for the engine parameter data set compared with the average value.

Since NO_x is the most important parameter of interest for the engine dynamometer testing, engine parameter data sets where the NO_x emissions differed by more than one standard deviation from the mean value were excluded from consideration. From the remaining cycles, a single cycle was selected considering each of the three factors listed above, with an emphasis on NO_x emissions that were comparable to the average value.

Once the most representative engine parameter data set was selected, the engine RPM and torque values were normalized to develop the engine cycle. The torque values were normalized from 0 to 100% for the maximum torque value based on the reference torque, the actual torque from the J1939 signal, and the frictional torque from the J1939 signal. Engine RPM was normalized from 0 to 100%, where 0 represents idle and 100% represents the maximum engine speed.

Testing and Final Development of Engine Dynamometer Test Cycles

The engine dynamometer test cycles were initially run on the dynamometer without any modification to evaluate how well the cycles could be followed on the engine dynamometer and to provide a comparison with the regression parameters currently used for the FTP. These initial tests, the cruise cycle showed reasonable agreement between the torque and rpm set points, but the light-duty UDDS showed a greater deviation from the set points than is typically seen for the FTP. The cycle did not meet the regression criteria used for the standard FTP and visual comparisons showed that the measured torque did not follow the setpoint torque during segment of the cycle associated with gearshifts. In an effort to improve the performance of the cycle on the engine dynamometer, additional tests were conducted with varying settings of the dynamometer controls, such as throttle response.

These issues are similar to those identified in the development work for the cycles for the ACES program, and can be attributed to the use of a clutch in the actual vehicle that removes the inertia load from the engine during gearshifting. Since the engine driveshaft is directly coupled to the dynamometer, this decoupling of the engine driveline can not be simulated on the engine dynamometer. As such, these events were considered to be representative of the behavior that can be expected when translating engine parameters between a vehicle chassis and an engine dynamometer.

To improve the operation of the cycles on the engine dynamometer, the cycles were modified slightly after the initial runs. Specifically, the rpm and torque values were set to zero for period of the cycle where the engine was in an idling segment. This eliminated small variations in rpm that occur near the idle point in real operation and small torque values that would likely be associated with auxiliary equipment when the engine was operating in the chassis. The normalized cycles in their final form are presented in Figures 1 and 2.

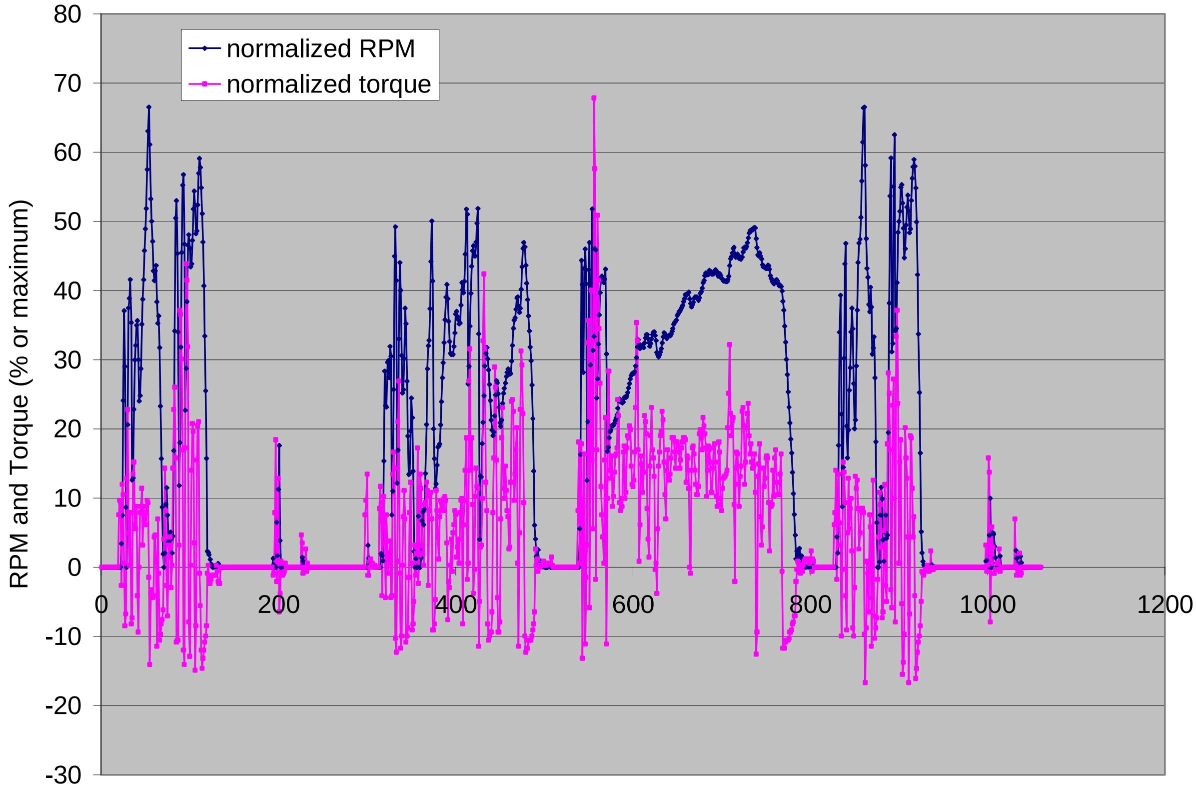


Figure 1. "Light-Duty" UDDS Engine Dynamometer Test Cycle for the 2006 Cummins ISM

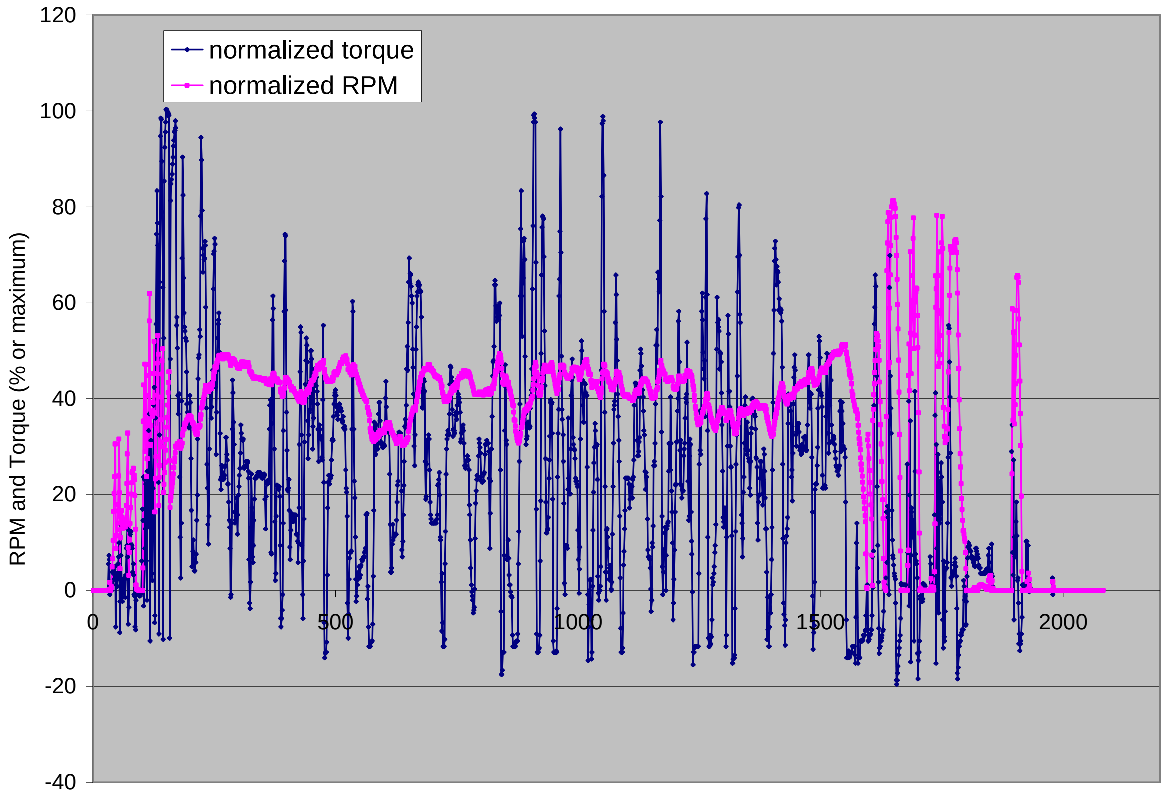


Figure 2. CARB Heavy Heavy-Duty Diesel Truck (HHDDT) Cruise for the 2006 Cummins ISM

Since the two developed cycles were inherently different from the FTP, new regression statistics were developed for each cycle. The new regression statistics were developed based on replicate runs of the cycles and comparisons between the regression runs for these cycles and those used for the FTP.

The techniques used for the development of the new regression statistics were similar to those used in the ACES program cycle development. The new regression statistics were scaled to comparable values for the FTP based on the tolerance, or how closely the parameter was met for the standard FTP. The equations utilized for these comparisons were the same as those utilized in the ACES programs, as provided below. In essence, these equations provide the same margin of error on a percentage basis for the new cycles, as is typically utilized in the FTP. These were utilized in cases where greater tolerance was needed for the statistics than is typically given in the FTP. In cases where the FTP regression statistics could be readily met without modification, the standard FTP criteria were maintained. In the case of the intercept for the power, examination of the data indicated that the power intercept was slightly greater than that for the FTP for the UDDS and cruise, but that the tolerance in this statistic could still be readily met by simply doubling the value of the intercept used in the FTP. A comparison of the FTP regression statistic criteria with the values obtained for the developed cycles is provided in Table 1.

$$X_{upper} = \left(\frac{EPA_{upper} - FTP_{actual}}{FTP_{actual}} \right) \cdot actual + actual$$

$$X_{lower} = -\left(\frac{FTP_{actual} - EPA_{lower}}{FTP_{actual}} \right) \cdot actual + actual$$

		Speed				Torque				Power			
		Slope	Intercept	SteYX	Rsq	Slope	Intercept	SteYX	Rsq	Slope	Intercept	SteYX	Rsq
FTP	upper	1.03	50	100	1	1.03	15	188.5	1	1.03	5	30.95	1
	lower	0.97	-50	0	0.97	0.83	-15	0	0.88	0.89	-5	0	0.91
UDDS	upper	1.03	41.8	44.1	1.00	0.91	28.9	108.1	0.880	0.92	30.4	13.9	0.89
	lower	0.97	-41.8	0	0.97	0.74	-28.9	0	0.775	0.79	-30.4	0	0.81
Cruise	upper	1.03	-7.9	44.1	1.00	1.05	22.2	153.8	1.01	1.02	26.6	21.7	0.99
	lower	0.97	7.9	0.0	0.97	0.84	-22.2	0.0	0.89	0.88	-26.6	0.0	0.90

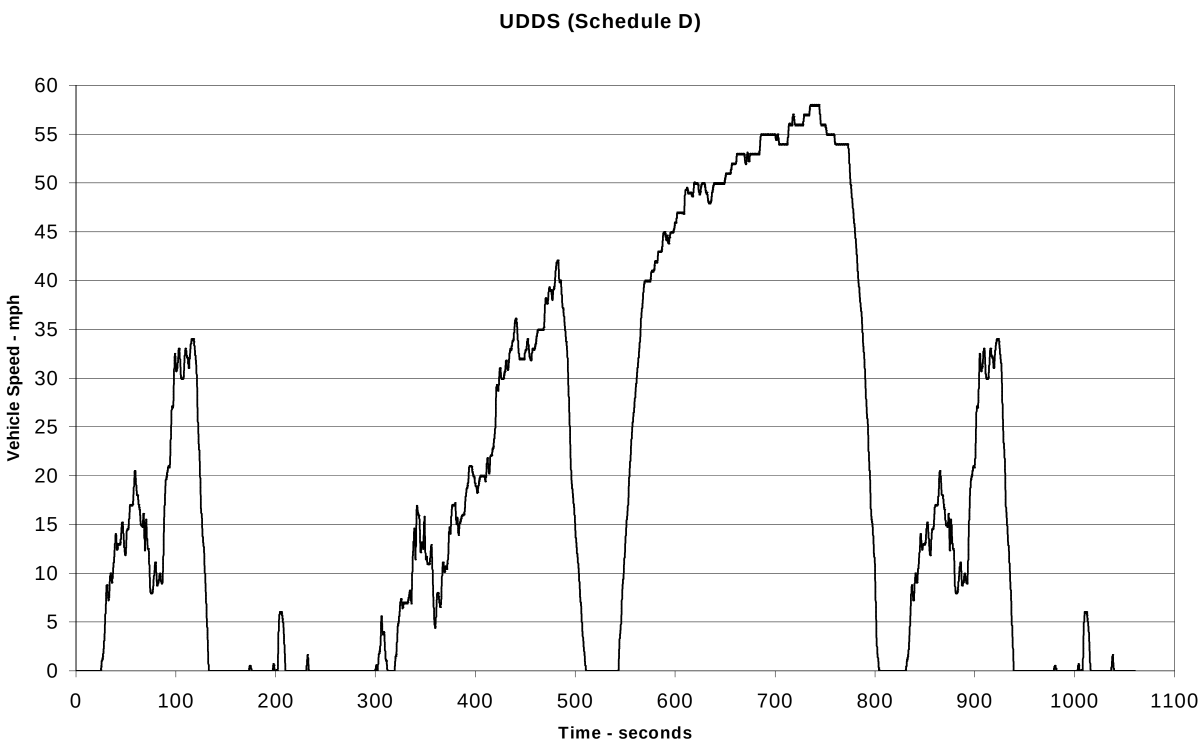
value doubled

Table 1. Comparison of regression statistics criteria for the FTP with values obtained for the UDDS and Cruise. Shaded areas indicate criteria where the values were greater than those for the FTP and were modified for the regression criterian.

Attachment A – Test Cycles

UDDS

Federal heavy-duty vehicle Urban Dynamometer Driving Schedule (UDDS) is a cycle commonly used to collect emissions data on engines already in heavy, heavy-duty diesel (HHD) trucks. This cycle covers a distance of 5.55 miles with an average speed of 18.8 mph and maximum speed of 58 mph.



CARB Heavy Heavy-Duty Diesel Truck (HHDDT) Cruise Schedule

The CARB Heavy Heavy-Duty Diesel Truck (HHDDT) Cruise schedule is part of a four mode test cycle developed for chassis dynamometer testing by the California Air Resources Board with the cooperation of West Virginia University. This cycle covers a distance of 23.1 miles with an average speed of 39.9 mph and maximum speed of 59.3 mph.