Emission Testing of a 1976 Toyota with the TTC-L Lean Burn Engine

September 1976

Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
U.S. Environmental Protection Agency

Background

Lean Mixture combustion engines are attractive because of the low emissions and good fuel economy that are possible with a properly designed lean burn engine. Toyota Motor Company Ltd. has developed several small displacement (under 2 litres) lean burn engines, and early this year began selling a lean burn vehicle in Japan.

The Emission Control Technology Division (ECTD), because of its interest in evaluating developments in automotive technology, has recently tested several prototype lean burn vehicles. When Toyota offered to provide EPA a lean burn vehicle for emissions testing, ECTD was pleased to have the opportunity to evaluate this new technological development.

The Environmental Protection Agency receives information about many systems which appear to offer potential for emissions reduction or improvement in fuel economy compared to conventional engines and vehicles. EPA's Emission Control Technology Division is interested in evaluating all such systems, because of the obvious benefits to the Nation from the identification of systems that can reduce emissions, improve economy, or both. EPA invites developers of such systems to provide to the EPA complete technical data on the system's principle of operation, together with available test data on the system. In those cases in which review by EPA technical staff suggests that the data available show promise for the system, attempts are made to schedule tests at the EPA Motor Vehicle Emission Laboratory at Ann Arbor, Michigan. The results of all such tests are set forth in a series of Technology Assessment and Evaluation Reports, of which this report is one.

The conclusions drawn from the EPA evaluation tests are of limited applicability. A complete evaluation of the effectiveness of a system in achieving improvements on the different types of vehicles that are in actual use requires a much larger sample of test vehicles than is economically feasible in the evaluation test projects conducted by EPA. For promising systems it is necessary that more extensive test programs be carried out.

The conclusions from this EPA evaluation test can be considered to be quantitatively valid only for the specific test car used. However, it is reasonable to extrapolate the results from the EPA test to other types of vehicles in a directional or qualitative manner, i.e., to suggest that similar results are likely to be achieved on other types of vehicles.

Vehicle Description

The vehicle tested was a 1976 Toyota Corolla Liftback fitted with the TTC-L (Toyota Total Clean System - Lean Burn) lean burn engine and a five-speed manual transmission. The engine is an in-line four-cylinder of about 1600 cc displacement volume. The vehicle is described in detail on the following page.

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1976 Toyota Corolla Liftback
Emission control system - Toyota Lean Burn - TTC-L

Engine

type	4 Stroke Otto Cycle, OHV, In Line 4 cyl.
bore x stroke	3.35 x 2.76 in. (85 x 70 mm)
displacement	96.9 cu. in. (1588 cc)
compression ratio	9.0:1
maximum power @ rpm	68 bhp/51 kW at 5200 rpm
fuel metering	single 2-barrel carburetor
fuel requirement	regular unleaded; tested with Indolene HO, Unleaded, with .03 wt. % sulfur

Drive Train

transmission type	5 speed manual
final drive ratio	3.91 to 1

Chassis

type	Unitized body, front engine, rear drive
tire size	165 SR 13
curb weight	2250 pounds
inertia weight	2500 pounds
passenger capacity	4

Emission Control System

basic type	TTC-L, Lean burn engine with divided chamber (Turbulence Generating Pot-TGP), Exhaust Port Liners, and Heat Shielded Exhaust Manifold

The engine is a modified version of the Toyota 2T-C engine, with a turbulence generating pot (TGP) in the main combustion chamber to promote fast burning of lean mixtures. (See Figure 1).

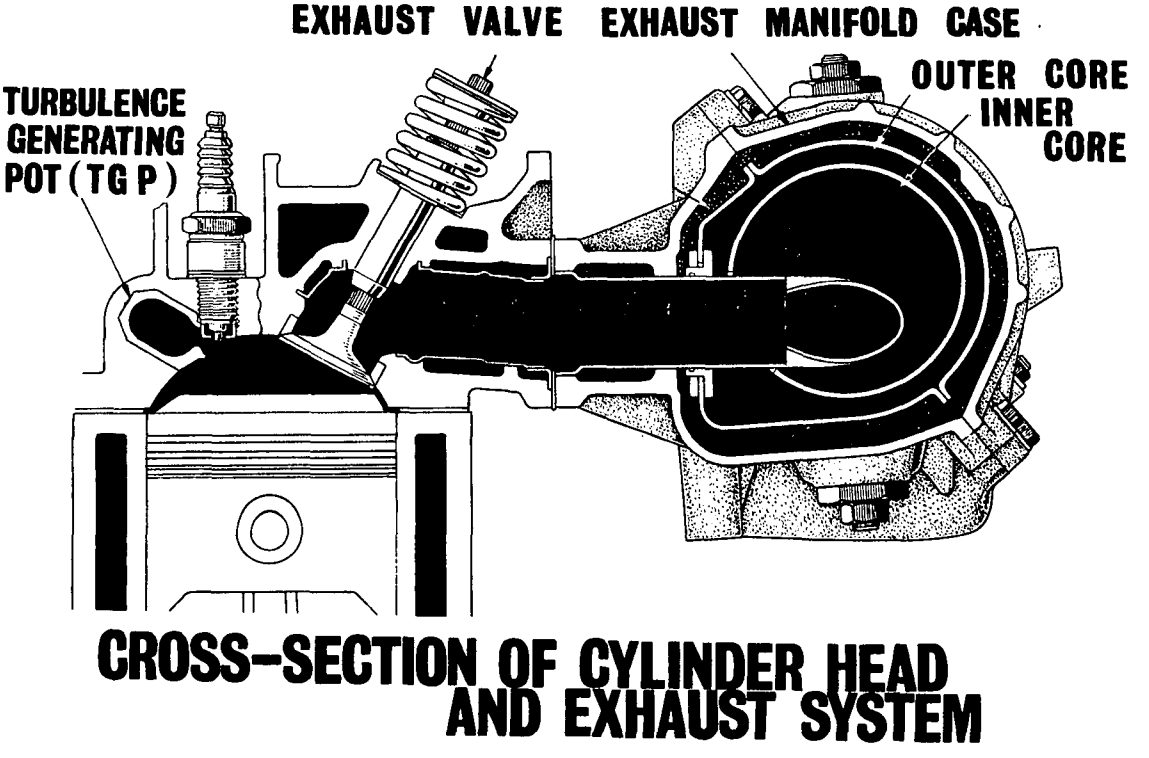

Figure 1
Toyota TTC-L Lean Burn Engine

A dual-electrode sparkplug is placed at the throat of the TGP to ensure ignition. According to Toyota, the mixture flow speed and sparkplug location are critical factors in obtaining good ignition with a homogeneous lean mixture.

Exhaust port liners and a heat shielded exhaust manifold are used to maintain high exhaust gas temperatures. Thus, HC and CO are further oxidized because the lean combustion process leaves enough oxygen in the exhaust.

An improved carburetor is used to reduce flow pulsations and deliver a homogeneous mixture to the combustion chamber. The principal change was the use of a sintered metal air bleed tube.

Toyota claims that this improved carburetor and the TGP have improved vehicle driveability and reduced HC, CO, and NOx emissions. Figure 2 below (furnished by Toyota) shows typical NOx formation characteristics for Toyota's conventional engines and their TTC-L lean burn engine.

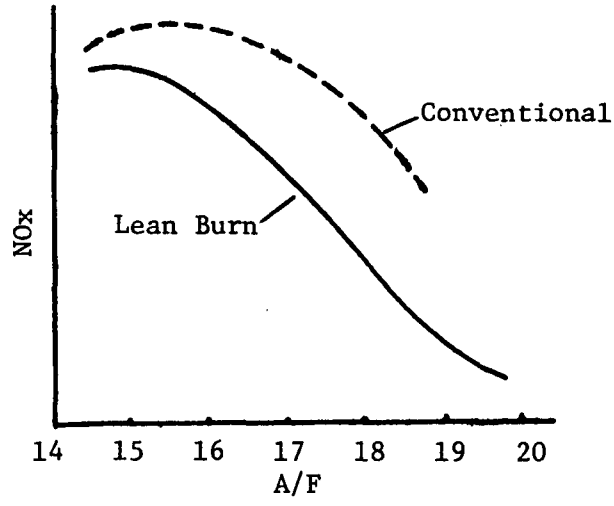

Figure 2
NOx Formation Characteristics

Test Procedures

Gaseous exhaust emissions tests were conducted according to the 1975 Federal Test Procedure ('75 FTP), described in the Federal Register of November 15, 1972, except that no evaporative emissions tests were conducted. Additional tests included the EPA Highway Fuel Economy Test (HFET), described in the Federal Register, Volume 39, Number 200, October 15, 1974, and steady state emissions tests.

These tests are conducted on a chassis dynamometer and employ the Constant Volume Sampling (CVS) procedure, which gives exhaust emissions of HC, CO, NOx and CO2 in grams per mile. Fuel economy is calculated by the carbon balance method. The fuel used was Indolene unleaded 96 RON gasoline. All tests were conducted using an inertia weight of 2500 pounds (1134 kg) with a road load setting of 9.4 horsepower (7.0 kW) at 50 miles per hour (80.5 km/hr). Three different shift patterns were employed.

The vehicle was also tested for sulfate emissions using the EPA sulfate test procedure, a description of which is given at the end of this report.

Since Toyota recommended shifting gears at what were considered very low speeds, tests were also conducted using alternate shift points to determine the effects on emissions and fuel economy. The shift patterns used were:

1 Toyota recommended shift pattern for TTC-L vehicle.

2 Toyota recommended shift pattern for U.S. Toyota Corolla.

3 EPA shift pattern for 4-speed vehicles (marked on driver's aid strip chart) when none is specified by manufacturers.

Shift Pattern	Shift point 1-2	Shift point 2-3	Shift point 3-4	Shift point 4-5
1	10 mph	20 mph	26 mph	45 mph
2	12 mph	22 mph	30 mph	
3	15 mph	25 mph	40 mph	

Test Results

Exhaust emissions data, summarized below, showed that the Toyota TTC-L vehicle was well within the levels required by the 1977 Federal emissions standards of 1.5 gm/mi HC, 15.0 gm/mi CO, 2 gm/mi NOx. However, the vehicle did not meet the statutory 1978 emission standards of .41 gm/mi HC, 3.4 gm/mi CO, .4 gm/mi NOx. Detailed results appear later in this report.

The test results for shift pattern 1 are listed below. Results are listed in Tables 1 and 2 for the other shift patterns.

	'75 FTP Composite Mass Emissions grams per mile (grams per kilometre)(1)				
	HC	CO	CO2	NOx	Fuel Economy (fuel consumption)
Shift pattern 1 (average of 7 tests)	1.14 (.71)	6.43 (4.00)	295 (183)	1.55 (.96)	28.7 miles/gal (8.2 litres 100/km)
1977 Federal Standards	1.5	15		2.0	

(1) Values in parentheses denote metric units.

On the EPA Highway Fuel Economy Cycle the results were:

EPA Highway Fuel Economy Test Mass Emissions
grams per mile
(grams per kilometre) (1)

	HC	CO	CO_2	NOx	Fuel Economy (Fuel consumption)
Shift pattern 1 (average of 7 tests)	.09	2.40	229	1.35	38.2 miles/gal
	(.06)	(1.49)	(142)	(.84)	(6.2 litres/100km)

Steady State fuel economy results were:

Speed mph (mi/hr)	Gear	Fuel economy miles/gal	(Fuel consumption) litres/100km
15	2	29.5	(8.0)
30	3	35.5	(6.6)
30	4	46.5	(5.1)
45	4	40.0	(5.9)
45	5	44.2	(5.3)
60	5	37.1	(6.3)

A comparison of the test vehicle's combined city/highway fuel economy with that of the Toyota Corolla tested for compliance with 1977 standards, showed that the test car had essentially the same fuel economy. When compared to all vehicles in the same inertia weight class (2500 lbs) the test car showed a 13% fuel economy improvement.

City/Highway Combined

	Fuel Economy miles/gal	(Fuel consumption) litres/100km
Toyota TTC-L (96.9 CID)	32.3	(7.3)
Toyota Corolla (1977 Certification vehicle) (96.9 CID)	31.8	(7.4)
Average of all 2500 lb 1977 Vehicles (avg. 98.1 CID)	28.7	(8.2)

(1) Values shown in parentheses denote metric units.

In calculating city/highway combined fuel economy, the urban fuel economy is weighted 55% and the highway fuel economy is weighted 45% to account for the 55/45 ratio of urban to rural mileage accumulation. The following equation is used:

$$MPG_{combined} = \frac{1}{\frac{.55}{MPG_{urban}} + \frac{.45}{MPG_{highway}}}$$

The tests using shift pattern 2 (See Tables 1, 2, and 3) showed no significant differences in emissions from shift pattern 1. However, using shift pattern 3 resulted in 10% lower fuel economy over the 75 FTP, when compared to shift pattern 1.

In tests conducted by Toyota at their emissions laboratory, the vehicle achieved approximately 6% better fuel economy than was achieved at the EPA laboratory in initial testing. Some previous test programs had shown better correlation between EPA and Toyota test facilities. Normally ECTD conducts only three tests in its confirmatory evaluation programs. However, because of the importance of fuel economy, ECTD conducted additional tests to investigate this 6% difference in fuel economy. These added tests used an EPA dynamometer test facility that had correlated well with Toyota's laboratory. No significant differences between EPA dynamometers were observed for these additional tests. Therefore all EPA test results were averaged together.

Sulfate emission test results are summarized in Table 5. Over the sulfate cycle the vehicle emitted about .4 milligrams of sulfuric acid per mile.

For comparison, typical vehicle sulfate emission rates (as found in the EPA sulfate baseline study*) are:

Catalyst vehicles with excess air - about 30 mgm/mile H_2SO_4 (range 0.3-96)

Catalyst vehicles without excess air - about 17 mgm/mile H_2SO_4 (range 0.5-83)

3-way catalyst vehicles - 1 mgm/mile H_2SO_4

Non-catalyst vehicles - 1 mgm/mile H_2SO_4

The large range in sulfate levels is due to the wide variations in technologies among the many vehicles tested.

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* Internal report "Test Report, Automotive Sulfuric Acid Baseline Program, " EPA, Emission Control Technology Division, January 1976.

The Toyota TTC-L vehicle had excellent driveability, and the engine ran quietly and smoothly. With all shift patterns the vehicle accelerated well enough to follow the prescribed driving schedules. No cold start problems were encountered. The vehicle performed equally well when it was driven on the road for a driveability evaluation. However, the various drivers preferred to shift at much higher speeds when not using Toyota's shift pattern, in order to maintain what were considered more normal acceleration rates.

Conclusions

At low mileage this Toyota Corolla equipped with the TTC-L lean burn system met the emission levels required by the 1977 Federal Standards. No catalyst aftertreatment was employed.

This system had a significant fuel economy advantage relative to conventional engines tested for 1977 emission standard certification in the same weight class.

Sulfate emission levels were found to be similar to non-catalyst vehicles.

Table 1

75 FTP Mass Emissions
grams per mile

	Bag 1 Cold Transient					Bag 2 Hot Stabilized					Bag 3 Hot Transient				
	HC	CO	CO_2	NOx	Fuel Economy mpg	HC	CO	CO_2	NOx	Fuel Economy mpg	HC	CO	CO_2	NOx	Fuel Economy mpg
77-2497 (1)	1.77	11.43	316	2.05	26.1	1.02	5.95	313	1.22	27.3	1.08	5.48	276	1.80	30.8
77-2501 (1)	1.59	10.71	313	2.15	26.5	.95	5.75	311	1.35	27.4	1.07	5.86	278	1.89	30.6
77-2800 (1)	1.56	8.76	299	1.88	28.0	1.03	5.73	294	1.01	29.0	1.10	5.13	263	1.68	32.3
77-4289 (1)	1.70	9.45	305	2.19	27.3	.87	5.57	298	1.21	28.6	1.03	5.21	273	1.81	31.2
77-4323 (1)	1.60	10.50	309	2.17	26.9	.98	5.04	291	1.08	29.4	1.08	4.87	265	1.98	32.2
77-4344 (1)	1.78	10.46	311	2.10	26.6	1.02	5.31	303	1.16	28.2	1.12	4.68	268	1.83	31.8
77-4348 (1)	1.63	10.09	313	2.08	26.6	.92	5.87	308	1.26	27.7	1.12	5.07	274	1.87	31.1
77-2581 (2)	1.65	10.50	330	2.24	25.2	.86	6.15	328	1.18	26.1	.99	5.00	276	1.92	30.9
77-2583 (3)	1.34	10.52	340	2.12	24.6	.92	6.26	346	1.21	24.7	1.10	4.65	300	1.61	28.5

Table 2

75 FTP Composite Mass Emissions
grams per mile

Test Number	HC	CO	CO_2	NOx	Fuel Economy mpg
77-2497 (1)	1.19	6.95	303	1.55	27.9
77-2501 (1)	1.12	6.80	303	1.66	28.0
77-2800 (1)	1.16	6.19	286	1.37	29.6
77-4289 (1)	1.08	6.27	293	1.58	29.0
77-4323 (1)	1.13	6.11	288	1.55	29.5
77-4344 (1)	1.20	6.20	295	1.54	28.8
77-4348 (1)	1.12	6.52	300	1.60	28.3
77-2581 (2)	1.06	6.73	314	1.60	27.1
77-2583 (3)	1.06	6.69	332	1.51	25.7

(1) Shift points 1-2 at 10 mph, 2-3 at 20 mph, 3-4 at 26 mph, 4-5 at 45 mph
(2) Shift points 1-2 at 12 mph, 2-3 at 22 mph, 3-4 at 30 mph,
(3) Shift points 1-2 at 15 mph, 2-3 at 25 mph, 3-4 at 40 mph,

Table 3

Highway Fuel Economy Test

Mass Emissions
grams per mile

Test Number	HC	CO	CO_2	NOx	Fuel Economy MPG
77-2496 (1)	.09	2.29	232	1.22	37.6
77-2502 (1)	.09	2.26	229	1.37	38.1
77-2728 (1)	.09	2.45	221	1.23	39.4
77-4325 (1)	.11	2.47	228	1.41	38.4
77-4326 (1)	.10	2.46	232	1.43	38.5
77-4345 (1)	.09	2.45	227	1.39	38.5
77-4349 (1)	.09	2.40	236	1.39	36.9
77-2582 (2)	.11	2.33	227	1.31	38.4
77-2584 (3)	.09	1.48	237	1.53	37.1

(1) Shift points 1-2 at 10 mph, 2-3 at 20 mph, 3-4 at 26 mph, 4-5 at 45 mph.

(2) Shift points 1-2 at 12 mph, 2-3 at 22 mph, 3-4 at 30 mph, 4-5 at 40 mph.

(3) Shift points 1-2 at 15 mph, 2-3 at 25 mph, 3-4 at 40 mph.

Table 4

Steady State Mass Emissions

grams per mile

Test Number	Speed	Gear	HC	CO	CO	NOx	Fuel Economy, mpg
77-2503	Idle *	N	.19	.97	33	.02	.23
77-2503	15	2	.87	4.43	291	.32	29.5
77-2503	30	3	.03	2.40	246	.61	35.5
77-2504	30	4	.17	2.95	186	.51	46.5
77-2504	45	4	.02	1.95	219	.89	40
77-2505	45	5	.04	2.48	197	.86	44.2
77-2505	60	5	.01	1.21	237	2.13	37.1

* grams per minute/gallons per hour

Table 5

Mass Emissions from Sulfate Tests
grams per mile

Test Number	Test Type	HC	CO	CO2	NOx	Fuel Economy, mpg	H_2SO_4*	% Conversion**
77-2516	75 FTP (Composite)	1.15	6.36	300	1.66	28.3	.38	.4
77-2518	HFET	.18	2.41	233	1.52	37.4	.65	.9
77-2517	SET	.35	3.38	234	1.24	36.9	.39	.6

* H_2SO_4 emissions are in milligrams per mile.

** Percent conversion of fuel sulfur to sulfuric acid

Toyota Lean Burn System TTC-L

Procedures used to measure sulfate emissions

1. The fuel was drained from the test vehicle. The vehicle was refueled with unleaded Indolene HO gasoline containing 0.03% sulfur by weight.

2. The vehicle was prepped by driving the vehicle over one LA-4 cycle to precondition the vehicle.

3. The following sequence of test cycles was used to measure sulfate emissions.

a) 75 FTP
b) Sulfate Emissions Test (SET)
c) HFET