

A Second Evaluation of the  
Yamaha Lean Combustion Engine System

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Technology Assessment and Evaluation Branch  
Emission Control Technology Division  
Office of Air and Waste Management  
Environmental Protection Agency

Background

The Environmental Protection Agency receives information about many systems which appear to offer potential for emission reduction or fuel economy improvement 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, attempts are made to schedule tests at the EPA Emissions Laboratory at Ann Arbor, Michigan. The results of all such test projects 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 necessarily of limited applicability. A complete evaluation of the effectiveness of an emission control system in achieving performance improvements on the many 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 the 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.

The Emission Control Technology Division (ECTD) of the Office of Mobile Source Air Pollution Control had previously tested the Yamaha Lean Combustion System (LCS) in August 1974 (ECTD report 75-8). The vehicles tested had very low pollutant emissions but had poor fuel economy. ECTD agreed to perform additional confirmatory tests if Yamaha was able to make significant fuel economy improvements and still achieve low emissions.

Subsequent to the EPA tests Yamaha improved fuel economy and built a second generation prototype system. ECTD was contacted by representatives of Yamaha International Company in January 1975 about confirmatory testing of the prototype second generation system. Consistent with ECTD's continuing interest in the evaluation of advanced automotive emission control technology, a test program was conducted by the Technology Assessment and Evaluation Branch.

### Vehicle Description

The vehicle tested was a Toyota Corolla with a LCS four cylinder 1588 cubic centimeter dual overhead cam engine and a 5-speed manual transmission. The car is described in detail in the Vehicle Description Table on the following page.

The Yamaha LCS is a lean mixture combustion system. The carburetor, intake manifold, and cylinder head incorporate a number of proprietary modifications to improve the quality of the fuel-air mixture and to improve the distribution of the mixture. This allows the engine to achieve the advantages of low hydrocarbon, carbon monoxide, and nitrogen oxide emissions resultant from lean operation (air fuel ratios between 17:1 and 18:1). The exhaust manifold was modified to act as a low temperature thermal reactor and thereby promote HC and CO oxidation reactions in the exhaust. Yamaha was able to attain low pollutant lean combustion without the need for fuel injection, dual intake passages, special valves or an auxiliary combustion chamber. The company's lean combustion technique permits its engine to achieve low pollutant emissions without exhaust gas recirculation (EGR), air injection, or a catalytic converter. (The vehicle tested previously used EGR.)

Yamaha claims its system requires no significant modifications to the basic engine design and causes less than 5% power loss. No emission deterioration data has yet been established, however in EPA judgement the system uses low deterioration components. Although the DOHC engine used in the test vehicle is not sold in the U.S., Yamaha believes its system is applicable to most engines. Yamaha considers its test vehicle to be a stage of development in a continuing effort. EPA has insufficient technical data to fully evaluate the above claims associated with the Yamaha system and therefore cannot confirm them.

### Test Procedure

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 Cycle and steady state emissions test. All tests were conducted using an inertia weight of 2250 pounds (1020 kg) with a road load setting of 8.8 horsepower (6.6 kW) at 50 miles per hour (80.5 km/hr).

## TEST VEHICLE DESCRIPTION

Chassis model year/make - 1974 Toyota Corolla  
 Emission Control system - Yamaha LCS

Engine

type . . . . . cycle, DOHC, 4 cyl., inline, Otto Cycle  
 bore x stroke . . . . . 3.35 x 2.76 in./85.0 x 70.0 mm  
 displacement . . . . . 96.9 CID/1558 cc  
 compression ratio . . . . . 9.0:1  
 maximum power @ rpm . . . . . in excess of 76 bhp/56.7 kW @ 3800 RPM  
 fuel metering . . . . . 2 barrel carburetor  
 fuel requirement . . . . . 91 RON unleaded

Drive Train

transmission type . . . . . 5 speed manual (3.587, 2.022, 1.384, 1.000,  
 final drive ratio . . . . . 4.30:1 .861)

Chassis

type . . . . . unitized body/frame, front engine, rear  
 tire size . . . . . 165 SR 14 wheel drive  
 curb weight . . . . . 2080 pounds  
 inertia weight . . . . . 2250 pounds  
 passenger capacity . . . . . 4

Emission Control System

basic type . . . . . lean combustion system  
 exhaust manifold . . . . . low temperature thermal reactor  
 durability accumulated on system . . 3400 miles/5500 km

Test Results

Exhaust emissions data, summarized below, showed that the Yamaha test car using their LCS achieved the levels of 1977 Federal Emission standards of .41 gm/mi HC, 3.4 gm/mi CO and 2.0 gm/mi NOx at low mileage. It also met the proposed 1978 California standards of .41 gm/mi HC, 9.0 gm/mi CO, and 1.5 gm/mi NOx.

'75 FTP Composite Mass Emissions  
grams per mile  
(grams per kilometre)

	<u>HC</u>	<u>CO</u>	<u>NOx</u>	<u>Fuel Economy</u> ( <u>Fuel Consumption</u> )
Average of 3 tests	.34 (.21)	3.00 (1.86)	1.44 (.89)	23.6 miles/gal (10.0 litres/100 km)

On the EPA Highway Cycle the results were:

EPA Highway Cycle Mass Emissions

Average of 4 tests	.01 (.01)	.37 (.23)	1.40 (.87)	36.3 miles/gal (6.5 litres/100 km)
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Steady state fuel economy results were:

<u>Speed</u> mph (km/hr)	<u>Gear</u>	<u>Fuel Economy</u> miles/gallon	<u>(Fuel Consumption)</u> litres/100 km
15 (24.1)	2nd	23.0	(10.2)
30 (48.3)	3rd	32.4	( 7.3)
45 (72.4)	4th	36.5	( 6.4)
45 (72.4)	5th	40.2	( 5.9)
60 (96.6)	5th	34.4	( 6.8)

In contrast to the previous vehicles, this test vehicle had no driveability problems. Detailed emission test results are given in tables at the end of this report.

Comparison of the test vehicle's fuel economy with certification results for 1975 vehicles of the same inertia weight (2250 pounds) showed that there was no fuel penalty. But several of these certification vehicles also met the 1977 emission standards.

### Fuel Economy Comparison

#### 1975 Certification Tests of 49 State Vehicles '75 FTP

Fuel Economy miles/gal (Fuel Consumption litres/100 km)	Average-13 Tests of 49 State Vehicles	Yamaha LCS
20.0 to 27.4 (11.8 to 8.6)	23.6 (10.0)	23.6 (10.0)

#### EPA Highway Cycle

30.4 to 41.1 (7.7 to 5.7)	36.2 (6.5)	36.3 (6.5)
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#### 1975 Certification Test of California Vehicles '75 FTP

Fuel Economy miles/gal (Fuel Consumption litres/100 km)	Average-6 Tests of California Vehicle	Yamaha LCS
20.6 to 27.4 (11.4 to 8.6)	23.7 (9.9)	23.6 (10.0)

#### EPA Highway Cycle

30.5 to 41.1 (7.7 to 5.7)	36.8 (6.4)	36.3 (6.5)
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### Conclusions

The Yamaha vehicle met the 1977 Federal Emission levels and was able to achieve this with a minimum of external engine emission control devices. There were no fuel economy penalties for the car when compared to current (1975 model) vehicles.

Yamaha is continuing development of its system. Presently the Company is testing larger vehicles (subcompact American car and 4000 pound inertia weight car). EPA has agreed to perform confirmatory testing of these vehicles if their emissions and fuel economy warrant it.

TABLE Ia

'75 FTP Mass Emissions  
grams per mile

<u>TEST NUMBER</u>	Bag 1 Cold Transient					Bag 2 Hot Stabilized					Bag 3 Hot Transient				
	HC	CO	CO2	NOx	FUEL ECONOMY MPG	HC	CO	CO2	NOx	FUEL ECONOMY MPG	HC	CO	CO2	NOx	FUEL ECONOMY MPG
21-7504	.86	7.04	389	2.15	22.1	.13	1.58	402	.99	21.9	.54	3.74	324	1.80	26.8
21-7540	.79	6.50	377	2.28	22.8	.12	1.68	391	.99	22.5	.30	2.39	316	1.81	27.7
21-7547*						.16	1.73	401	.94	22.0	.40	3.25	313	1.70	27.8
21-7585	.74	6.16	379	2.11	22.7	.14	1.57	389	.96	22.7	.37	2.80	309	1.72	28.2

TABLE Ib

'75 FTP Composite Mass Emissions  
grams per mile

<u>TEST NUMBER</u>	<u>HC</u>	<u>CO</u>	<u>CO2</u>	<u>NOx</u>	<u>COMPOSITE FUEL ECONOMY MPG</u>
21-7504	.39	3.29	378	1.45	23.1
21-7540	.31	2.87	367	1.48	23.8
21-7585	.33	2.85	365	1.40	23.9

\* Void; not used in averages.

TABLE II

EPA Highway Cycle Mass Emissions  
grams per mile

<u>TEST NUMBER</u>	<u>HC</u>	<u>CO</u>	<u>CO2</u>	<u>NOx</u>	<u>FUEL ECONOMY MPG</u>
21-7504	.01	.35	251	1.43	35.3
21-7540	.02	.42	246	1.48	36.0
21-7547	.01	.36	244	1.36	36.3
21-7585	.01	.35	236	1.34	37.5

TABLE III

Steady State Mass Emissions  
grams per mile

<u>TEST NUMBER</u>	<u>SPEED MPH</u>	<u>GEAR</u>	<u>HC</u>	<u>CO</u>	<u>CO2</u>	<u>NOx</u>	<u>FUEL ECONOMY MPG</u>
	0 (idle)	N	.02*	.34*	98*	.02*	N/A
	15	2	.03	1.22	383	.28	23.0
	30	3	.00	.33	273	.48	32.4
	45	4	.01	.25	242	.96	36.5
	45	5	.00	.29	220	.78	40.2
	60	5	.01	.24	258	2.13	34.4

\* Idle emission values are in grams per minute.