Evaluation of the Yamaha Lean Combustion Engine System - Emissions and Fuel Economy

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Technology Assessment and Evaluation Branch
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Background

The Environmental Protection Agency receives information about many devices for which emission reduction or fuel economy improvement claims are made. In some cases, both claims are made for a single device. In most cases, these devices are being recommended or promoted for retrofit to existing vehicles although some represent advanced systems for meeting future standards.

The EPA is interested in evaluating the validity of the claims for all such devices, because of the obvious benefits to the Nation of identifying devices that live up to their claims. For that reason the EPA invites proponents of such devices to provide to the EPA complete technical data on the device's principle of operation, together with test data on the device made by independent laboratories. In those cases in which review by EPA technical staff suggests that the data submitted holds promise of confirming the claims made for the device, confirmatory tests of the device are scheduled at the EPA Emissions Laboratory at Ann Arbor, Michigan. The results of such confirmatory 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 confirmatory tests are necessarily of limited applicability. A complete evaluation of the effectiveness of an emission control system in achieving its claimed 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 confirmatory test projects conducted by EPA. 1/ For promising devices it is necessary that more extensive test programs be carried out.

The conclusions from the EPA confirmatory tests can be considered to be quantitatively valid only for the specific type of vehicle used in the EPA confirmatory test program. Although it is reasonable to extrapolate the results from the EPA confirmatory 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, tests of the device on such other vehicles would be required to reliably quantify results on other types of vehicles.

1/ See Federal Register 38 FR 11334, 3/27/74, for a description of the test protocols proposed for definitive evaluations of the effectiveness of retrofit devices.

In summary, a device that lives up to its claims in the EPA confirmatory test must be further tested according to protocols described in footnote 1/, to quantify its beneficial effects on a broad range of vehicles. A device which when tested by EPA does not meet the claimed results would not appear to be a worthwhile candidate for such further testing from the standpoint of the likelihood of ultimately validating the claims made. However, a definitive quantitative evaluation of its effectiveness on a broad range of vehicle types would equally require further tests in accordance with footnote 1/.

During a June visit to the Japanese motorcycle industry, EPA personnel were informed by Yamaha of their developments in automotive emissions control technology. Interest in the automotive emissions control area stems from the little known fact that Yamaha is a manufacturer and supplier of automotive engines to the automotive industry. Yamaha claimed that their demonstration vehicle could meet the statutory HC and CO standards and 2.0 gm/mi NOx (1.24 gm/km) with a fuel penalty of about 7%. To confirm their results, Yamaha requested confirmatory tests at EPA on two vehicles in early stages of development.

Provided that the confirmatory testing proved successful, Yamaha also proposed that they build second generation prototypes for future EPA testing. (Subsequent to this test program, Yamaha has already provided EPA with data showing fuel economy improvement. On the basis of this data EPA and Yamaha have tentatively agreed to a confirmatory test program on two additional prototypes in the near future.)

Vehicles tested

The Yamaha Lean Combustion Engine System is a lean mixture combustion system. The carburetor and cylinder head incorporate a number of proprietary modifications to facilitate lean operation (air-fuel ratios between 17:1 and 18:1). The exhaust manifold was insulated to elevate temperature, and thereby promote HC and CO oxidation reactions in the exhaust. EGR is also employed. These modifications were incorporated in engines installed in a Toyota Corolla and Toyota Celica.

Yamaha considers their system to be a low cost, readily adaptable modification to existing engine systems during vehicle manufacturing. Presently, EPA has insufficient technical data to evaluate the additional costs associated with the Yamaha system and therefore cannot confirm this claim.

Vehicle Specifications	Yamaha Corolla	Yamaha Celica
Engine Type	Inline 4 cylinder	Inline 4 cylinder with DOHC
Transmission	M5	M5
Axle ratio	4.30	4.38
Inertia Weight	2250 pounds (1020 kilograms)	2500 pounds (1134 Kilograms)
Displacement	1600 CC	2000 CC
Carburetion	1-2V (1 Two-Barrel)	4-1V (4 single-barrel)

Yamaha considered the multiple carburetion of the Celica vehicle to be better suited to their lean burn concept than the single carburetor system of the Corolla. Both vehicles had accumulated approximately 4000 miles (7000 kilometres) with the Yamaha engines at the time of EPA testing.

Test Program

The vehicles arrived on Monday August 19, 1974 and were conditioned by driving the cars over the vehicle road preparation route and then, using a chassis dynamometer, the Federal driving cycle. The following tests were then conducted on the vehicles:

1. Corolla:

   A. Four cold start '75 Federal Test Procedures (FTP) at 2250 pounds (1020 kgm) simulated inertia weight. For one test the distributor was modified.

   B. Three highway fuel economy tests (FET) at 2250 pounds (1020 kgm) simulated inertia weight. For one test the distributor was modified.

   C. Steady state gaseous emissions testing at idle, 15 mph (24.1 km/hr), 30 mph (48.3 km/hr), 45 mph (72.4 km/hr), and 60 mph (96.5 km/hr).

2. Celica:

   A. Three cold start '75 FTP: two at 2500 pounds (1134 kgm) and one at 4000 pounds (1814 kgm) simulated inertia weight.

   B. Three highway FET: two at 2500 pounds (1134 kgm) and one at 4000 pounds (1814 kgm) simulated inertia weight.

   C. Steady State emissions testing at idle, 15 mph (24.1 km/hr), 30 mph (48.3 km/hr), 45 mph (72.4 km/hr) and 60 mph (96.5 km/hr).

The Corolla distributor advance was changed during the test program by Yamaha to improve fuel economy. The distributor was modified to give 5 degrees additional mechanical advance between 2000 and 2500 RPM while still giving the same maximum mechanical advance.

Since the Celica had considerably higher than normal horsepower for a car of its weight, it was tested at 4000 pounds (1814 kgm) inertia weight, in addition to the standard weight of 2500 pounds (1134 kgm), to evaluate the performance of the system when operated with a more typical power to weight ratio.

All EPA tests were run on leaded fuel, although either leaded or unleaded fuel may be used with the Yamaha Lean Combustion System.

In addition to the analysis for typical gaseous emissions the samples were analyzed for aldehydes using the MBTH (3-methyl, 2-benzothiazolinone) method. Fuel economy was calculated using the carbon balance technique. Because Yamaha had previously tested the cars using a leaded fuel, sulfate emissions were not attempted in order to prevent contamination of the EPA particulate tunnel. In addition the evaporative emission tests required in 1975 FTP were not attempted.

Test Results

Results of the emissions and economy tests on the Yamaha vehicles are detailed in Tables I, II, and III. Pollutant mass emissions are expressed in grams per mile. The fuel economy for the tests was calculated using the carbon balance technique and is expressed in miles per gallon. Equivalents of these emissions in grams per kilometre and fuel consumption in litres per 100 kilometres are given in parentheses.

Table I presents the results of the 1975 FTP emissions and fuel economy measurements. Composite results are:

	HC gm/mi (gm/km)	CO gm/mi (gm/km)	NO_x gm/mi (gm/km)	Fuel Economy (Consumption) MPG (litres/100 km) Urban	Highway
Yamaha Corolla (4 test average)	.36 (.22)	3.80 (2.36)	1.18 (.73)	16.0 (14.7)	28.7 (8.2)
Yamaha Celica (2500 lbs. test 16-5791)	.34 (.21)	2.95 (1.83)	1.54 (.96)	14.5 (16.2)	23.6 (10.0)
Yamaha Celica (4000 lbs.)	.46 (.28)	6.87 (4.27)	2.32 (1.44)	14.7 (16.0)	19.4 (12.1)

The Yamaha Corolla results demonstrate that levels of HC below the original (1976) statutory emissions standards can be achieved with this vehicle. CO levels were 12 percent above these standards and oxides of nitrogen levels were consistently below the 1975 interim emission standards. The high levels of HC and CO during bag 1 of test 16-5805 appeared to be associated with the excessive cranking by the EPA driver. For this test the fuel system was connected to a gasoline container for weighing the quantity of fuel used. It is believed that the cold start problem was possibly caused by the air in the fuel system due to incomplete purging of air in fuel system when it was reconnected.

When tested at the higher inertia weight, the Yamaha Celica easily met the 1975 vehicle certification levels. Urban fuel economy was nearly identical to that achieved at the lighter inertia weight. It should be noted however that the somewhat higher rear wheel tire losses that would have occurred if the car actually weighed enough to place it in the 4000 pound inertia weight class would have caused a slight increase in power requirements and a corresponding decrease in economy.

Fuel consumption was also checked by weighing the fuel for one test on each vehicle. The results show close areeement.

	Fuel Economy (Consumption) MPG (litres/100 km) calculated by	
	carbon balance	weight
Yamaha Corolla test 16-5807	16.4 (14.3)	15.9 (14.8)
Yamaha Celica test 16-5808	14.7 (16.0)	14.8 (15.9)

Aldehydes levels as measured by the EPA MBTH method are:

	Composite HC gm/mi (gm/km)	Ald'y gm/mi (gm/km)	% Ald'y
Yamaha Corolla test 16-5790	.34 (.21)	.0235 (.0146)	6.9%
Yamaha Celica test 16-5791	.34 (.21)	.0137 (.0085)	4%

In comparison with other late model cars, the Yamaha Lean Combustion Engine System appears to yield low aldehyde emissions.

Several driveability problems were encountered with both cars. The Corolla surged slightly during constant speed portions of the FTP. The Celica stalled at least once during each cold start when accelerated from idle. This occurred after the vehicle was running at least two minutes. The more experienced Yamaha driver was better able to anticipate the car's performance and experienced no stall problems.

Comparison of the vehicles' fuel economy with certification results for 1973 vehicles of similar weight and engine displacement is given in Table III. It is apparent that the Yamaha Lean Combustion Engine System had worse fuel economy that the certification vehicles when the standard test weights of 2250 and 2500 are considered. However, it should be noted that these vehicles are first generation prototypes and Yamaha has claimed that little attention was devoted to optimization of fuel economy. The comparison of the results using the 4000 pound test weight for the Celica are considered more representative of the potential of the system however since the Celica was the more refined of the two test vehicles and its power to weight ratio at a 2500 test weight was not representative of typical 2500 class cars.

Conclusions

1. On the basis of their initial tests, both EPA and Yamaha agree that the results are promising enough to warrant additional development by Yamaha. In particular, Yamaha will concentrate on fuel economy improvements and EPA will agree to test additional prototypes if fuel economy objectives are met.

2. The Yamaha Lean Combustion Engine System appears to have the potential to meet .41 gpm HC and 3.4 gpm CO standards without catalytic devices. A 2.0 gpm NOx standard appears to be achievable with Yamaha system, however, NOx standards significantly lower than this will require further development.

3. There were fuel economy penalties when compared to current (1975 model) vehicles achieving similar levels of pollutant emissions. The 4000 pound test however demonstrates some potential for achieving fuel economy equivalent to that shown by other control approaches.

4. Aldehyde emissions from the Yamaha Lean Combustion Engine System were lower than present production cars.

TABLE I
1975 FTP Results
Yamaha - Corolla

Test No.	Hydrocarbons gm/mi*				Carbon Monoxide gm/mi*				Oxides of Nitrogen gm/mi*				Calculated Fuel MPG** Consumption	
	Bag 1	Bag 2	Bag 3	Composite	Bag 1	Bag 2	Bag 3	Composite	Bag 1	Bag 2	Bag 3	Composite	75 FTP	Highway
*** 16-5769	1.72 (1.07)	.04 (.02)	.11 (.07)	.40 (.25)	11.72 (7.28)	.73 (.45)	1.65 (1.02)	3.24 (2.01)	2.12 (1.32)	.76 (.47)	1.21 (.75)	1.16 (.72)	16.6 (14.2)	29.6 (7.9)
16-5790	1.37 (.85)	.05 (.03)	.12 (.07)	.34 (.21)	16.15 (10.03)	.81 (.50)	1.72 (1.07)	4.21 (2.62)	2.13 (1.32)	.79 (.49)	1.17 (.73)	1.17 (.73)	15.5 (15.2)	28.5 (8.3)
16-5807	1.45 (.90)	.04 (.02)	.11 (.07)	.35 (.22)	16.72 (10.38)	.88 (.55)	1.95 (1.21)	4.43 (2.75)	2.20 (1.37)	.85 (.53)	1.33 (.83)	1.26 (.78)	15.7 (15.0)	--
16-5824	1.40 (.87)	.04 (.02)	.14 (.09)	.35 (.22)	9.70 (6.03)	1.22 (.76)	2.49 (1.55)	3.31 (2.06)	1.92 (1.19)	.83 (.52)	1.12 (.70)	1.13 (.70)	16.2 (14.5)	28.1 (8.4)
					Yamaha Celica									
*** 16-5791	75 FTP incomplete due to water leak requiring shutdown to repair leak													10.2 (23.1)
16-5791	1.17 (.72)	.11 (.07)	.15 (.09)	.34 (.21)	5.60 (3.48)	2.42 (1.50)	1.97 (1.22)	2.95 (1.83)	2.16 (1.34)	1.20 (.75)	1.73 (1.08)	1.54 (.96)	14.4 (16.3)	24.0 (9.8)
**** 16-5808	5.46 (3.39)	.20 (.12)	.20 (.12)	1.28 (.80)	10.11 (6.28)	3.24 (2.01)	2.28 (1.42)	4.39 (2.73)	2.17 (1.35)	1.22 (.76)	1.79 (1.11)	1.57 (.98)	14.6 (16.1)	
(1814 kgm) 16-5826	1.38 (.86)	.15 (.09)	.35 (.22)	.46 (.28)	11.60 (7.28)	3.71 (2.31)	9.32 (5.79)	6.87 (4.27)	2.96 (1.84)	1.89 (1.17)	2.64 (1.64)	2.32 (1.44)	14.7 (16.0)	19.4 (12.1

* ( ) gm/km
**( ) Litres/100km
*** Yamaha Driver
**** Excessive cranking during startup - (see text)

TABLE II

Steady State Emissions
1600 cc Yamaha Corolla

Test No.	Speed	Gear	HC gm/mi*	CO gm/mi*	NOx gm/mi*	Fuel Economy
16-5770	Idle (gm/5-min.)	N	0	.26 (.16)	.51 (.32)	NA
16-5771	15 mph. 24.1 km/mi	2	0	.09 (.06)	.30 (.19)	14.3 (16.5)
16-5772	(30 mph) 48.3 km/hr	3	0	.08 (.05)	.37 (.23)	23.1 (10.2)
16-5773	(45 mph) 72.4 km/hr	4	0	.13 (.08)	.59 (.37)	29.1 (8.1)
16-5774	(60 mph) 96.5 km/hr	5	0	.27 (.17)	1.05 (.65)	28.8 (8.2)
			2000 cc Yamaha Celica			
16-5775	Idle (gm/5-min.)	N	.01 (.01)	.68 (.42)	.36 (.22)	NA
16-5777	(15 mph) 24.1 km/hr	2	.01 (.01)	.87 (.54)	.52 (.32)	17.7 (30.6)
16-5778	(30 mph) 48.3 km/hr	3	.0 (.00)	.18 (.11)	.55 (.34)	20.2 (11.6)
16-5779	(45 mph) 72.4 km/hr	4	.0 (.00)	.13 (.08)	.89 (.55)	23.3 (10.1)
16-5780	96.5 km/hr (60 mph)	5	.0 (.00)	.16 (.10)	2.03 (1.26)	22.1 (10.6)

* ( ) gm/km
** ( ) Litres/100 km

TABLE III

Fuel Economy of Yamaha Vehicles and 1975 Vehicles

	Test Inertia wt. lbs.	Fuel Economy (Consumption) MPG(litres/100 km) Urban Cycle	Highway Cycle
Yamaha Corolla	2250	16.0 (14.7)	28.7 (8.2)
1975 Vehicles	2250	20.6 to 24.8 (9.5 to 11.4)	30.5 to 41.1 (5.7 to 7.7)
Yamaha Celica	2500	14.5 (16.2)	23.6 (10.0)
1975 Vehicles	2500	13.8 to 23.4 (10.0 to 17.0)	20.1 to 38.4 (6.2 to 11.7)
Yamaha Celica	4000	14.7 (16.0)	19.4 (12.1)
1975 Vehicles	4000	11.2 to 15.3 (15.4 to 21.0)	16.5 to 25.0 (9.4 to 14.3)

1975 Vehicle Data represents the calculated fuel economy from vehicle emission certification tests. Above data is for vehicles equipped with manual transmissions.