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An Evaluation of Two Toyo Kogyo 1975 Prototypes With Rotary Engines

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Background

Of all automobile manufacturer's who testified at the April 1972 Suspension Hearings, Toyo Kogyo was the most optimistic about the possibility of meeting the 1975 Federal exhaust emission standards. Toyo Kogyo had achieved the levels required for 1975, at low mileage, and had initiated 50,000-mile durability tests to prove their capability to remain below the required levels. This past October, when the manufacturers submitted their annual status reports on their progress toward meeting the 1975 standards, EPA learned that Toyo Kogyo had completed 50,000 miles of durability on one of their 1975 prototypes, a rotary engined Mazda RX3. Emission levels were still below the 1975 requirements. A letter was written to Toyo Kogyo offering confirmatory testing in EPA's Ann Arbor laboratory. The offer was accepted and two vehicles, the RX3, which had completed 50,000 miles,and and RX4, with 4000 miles accumulated, were delivered for testing late in January.

Vehicles Tested

Both vehicles supplied by Toyo Kogyo were equipped with rotary engines using thermal reactors for the control of unburned hydrocarbons (HC) and carbon monoxide (CO). No control systems (such as exhaust gas recirculation) for the control of oxides of nitrogen (NOx) were required to achieve the 1975 levels because of the light weight of the Mazda vehicles (2350# and 2600# for the RX3 and RX4, respectively) and the inherently lower NOx emissions of rotary engines.

The RX3 vehicle was the smaller of the two. Toyo Kogyo estimated that this vehicle would be in the 2750 pound inertia weight* class for 1975. The two rotor engine installed in this vehicle, had a swept volume of 70 cubic inches. The vehicle was equipped with a four speed manual transmission. Before the EPA testing, the RX3 had completed a 50,000-mile AMA durability run. Toyo Kogyo's data indicated that the vehicle could successfully certify for 1975.

The RX4 vehicle will be in the 3000 pound inertia weight class for 1975. The two rotor engine in this vehicle had a swept volume of 80 cubic inches. This vehicle was equipped with an automatic transmission. Four thousand miles had been accumulated on the vehicle before the EPA testing.

*Note: inertia weight = curb weight + 300 pounds, rounded to the nearest 250 pounds.

Both vehicles used air-cooled thermal reactors with "modulated" air injection. Air injection rate is kept proportional to engine speed and load by a special control valve. Most manufacturers use an air injection system which does not match the injection rate with the load of the engine. A non-proportional system can cause a loss of emission control at light loads due to an excess of injected air. On the Toyo Kogyo system, air which is not injected into the core of the reactor is directed into an annulus surrounding the reactor for cooling. Above speeds of about 65 mph, all of the air is injected into the annulus for cooling and none is injected into the reactor core. Data reported by Toyo Kogyo indicate that a substantial loss of HC and CO control occurs during this condition.

Manual chokes were also used on both vehicles. Toyo Kogyo representatives indicated, however, that automatic chokes are scheduled for production in 1975.

Toyo Kogyo had operated these vehicles on a "low lead" fuel containing .36 grams per gallon of Tetra-ethyl lead and .013% sulfur (by weight). This fuel had a Research Octane Number of 91 and contained 6.1% Olefins, 31.3% aromatics, and 62.6% paraffins. The EPA testing was done on "Indolene Clear" which contains about .05 grams per gallon lead. The Toyo Kogyo representatives who accompanied the two vehicles reported that their engines were not sensitive to lead level. Lead is not required for octane improvements or lubrication, neither is "lead free" fuel required to prevent system deterioration.

Test Program

Four different types of emission tests were performed during the EPA evaluation:

1. 1975 Federal Test Procedure (FTP) at the standard test weights (2750# for RX3, 3000# for RX4).

2. Hot start 1972, 2-bag FTP's on the RX4 with a richer carburetor.

3. 1975 FTP on the RX3 at an elevated (3500#) inertia weight.

4. Steady state tests on both vehicles at idle, 15,30,45, and 60 mph.

Gaseous emissions (HC, CO, NOx, and CO_2) and fuel economy were determined during each type of test. A description of the Federal Test Procedure for exhaust emissions is enclosed (Attachment I).

Test Results

Results are summarized in Tables I, II, III, and IV. Table I lists the results on the 1975 FTP for both vehicles at their standard test weights. Toyo Kogyo's data from their last series of tests run on these cars is also included for comparison. Every test on each vehicle was below the levels required for 1975. The 50,000-mile RX3 averaged approximately one-half of the required levels for HC and CO and one-third of the required NOx level.

One test on the RX3 (not reported in Table I) had to be voided because the EPA driver did not use the correct choking procedure. The Toyo Kogyo rotarys are very sensitive to the choking procedure used. Tests were conducted using continuous analysis of the exhaust to see the effect of choking procedure on the hot restart. With no choke the HC levels remained high for a much longer period of time, levels above 100 ppm propane (dilute) were recorded one minute after start-up. With the choke, however, the HC levels stayed below 100 ppm after only 15 seconds. Fortunatly, since Toyo Kogyo is planning to equip production vehicles with automatic chokes, this critical operation will not be left up to the driver.

The fuel economy data appearing on Table I was calculated using a carbon balance technique. The 12.36 and 11.92 mpg, recorded for the RX3 and RX4, respectively, indicates that no loss in fuel economy has occurred in meeting the 1975 levels. 1973 rotary Mazdas in the same weight class had almost identical fuel economy. It should be noted, however, that Mazda rotarys seem to get poorer fuel economy than vehicles with conventional engines. EPA tests indicate that the average fuel economy for Mazda rotarys is 30% worse than the average of all vehicles in their respective weight classes.

Table II shows the emissions during steady state operation for both vehicles. The extremely low HC emission level at each point is a characteristic of vehicles with emissions controlled by thermal reactors. CO emissions are also quite low at each point. NOx emissions continually increase as speed increases for both vehicles. Calculated fuel economy was better at every steady state cruise than during the LA4 (Federal) driving cycle. This is to be expected since fuel economy is adversely affected by the stop and go type driving which is represented by the LA4 cycle. Testing at 65 mph and above was not possible due to the limitation of the particular chassis dynamometers used, but it should be noted that a loss of HC and CO emission control is expected at such speeds when the air injection does not enter the reactor core. Toyo Kogyo representatives were unable to provide any data which indicated that vehicle or engine speeds were the most meaningful parameters to trigger the air injection by-pass valve. The possibility of changing the activating signal to load or reactor temperature was discussed.

The results of the testing of the RX3 vehicle at elevated inertia weight appears in Table III. Since Toyo Kogyo vehicles have relatively high power to weight ratios, it is not unrealistic to assume that the engine from the 2750# test weight class RX3 would do an acceptable job of propelling a vehicle in the 3500# test weight class. Comparing the results of the test at the 3500# weight with the average of the tests at the 2750# weight, it can be seen that very little emission control was sacrificed. The fuel economy compared to the average 1973 vehicle in the 3500# class indicates a 20% penalty. This is less of a penalty than was indicated by comparing the results at 2750# with the average 1973 vehicle in the 2750# class, indicating that the rotary Mazda's fuel economy problems are due in part to the high power to weight ratios of Mazda vehicles. It should be noted that the Toyo Kogyo personnel made a modification to the carburetor on the RX3 prior to the testing at 3500#. This modification either delayed or eliminated the opening of the secondaries in the carburetor. The attached driver's trace (Figure 1.) indicates that the vehicle could not quite keep up with the hardest acceleration of the cycle with the modified carburetor.

In Table IV appears the results of the hot start testing of the RX4 with the richer carburetor. In this configuration fuel economy was somewhat adversely affected. NOx levels, however, were only 17% higher than the requirement for 1976 of .40 grams per mile (gpm). HC and CO levels should not be directly compared to the 1975 or 1976 standards since these tests were "hot" rather than "cold" start. The Toyo Kogyo representatives indicated that the HC emissions would probably be below the 1975 and 1976 requirement during a cold start test, but CO emissions would be a problem. It should be noted that the .47 gpm NOx level was achieved without EGR. Toyo Kogyo representatives indicated that EGR, a common control technique for reciprocating engines, also has a beneficial effect on NOx emissions from the rotary engine.

Although not reported in the tables, the RX4 vehicle was also tested for aldehyde emissions using a wet chemical technique. The formaldehyde level of the exhaust was too low to be accurately determined by the procedure used. The formaldehyde level is well below the levels of uncontrolled conventional engines.

The driveability of the RX4 vehicle was evaluated on the road and there were no problems encountered. The engine was very responsive and there were no hints of hesitation or stumbling. Acceleration was very good, typical of current Mazdas which are not known for having any trouble keeping up with traffic.

Conclusions

1. Toyo Kogyo appears to have successfully demonstrated the ability to certify for 1975.

2. The two 1975 prototypes did not demonstrate any fuel economy penalty compared to current Mazda vehicles. There were no driveability problems encountered.

3. The Toyo Kogyo rotary engine and control system will also achieve the 1975 levels at higher test weights than required for Mazda vehicles.

4. There does not appear to be a formaldehyde emission problem associated with the rotary engine/thermal reactor concept.

5. Additional NOx control will be necessary to reach the 1976 levels, but it should be noted that the vehicles tested did not use EGR.

TABLE I

Toyo Kogyo 1975 Prototypes With Rotary Engines
1975 Federal Test Procedure
(emission data in grams per mile)

Vehicle	Lab	Test Number	HC	CO	NOx	MPG
50,000 mile car MCCIII No. 1 RX3, 4-speed 2750# Inertia	EPA	16-0205	.25	2.09	1.04	12.38
	EPA	16-0209	.12	1.53	.98	12.64
	EPA	16-0227	.25	1.76	.94	12.07
	EPA	AVERAGE	.21	1.79	.99	12.36
	Toyo Kogyo	1-1	.316	2.40	.96	---
	Toyo Kogyo	1-2	.326	2.32	.97	---
	Toyo Kogyo	1-3	.369	2.66	.95	---
	Toyo Kogyo	AVERAGE	.337	2.46	.96	---
4,000 mile car MCCIV No. 1 RX4 automatic 3000# Inertia	EPA	16-0206	.29	2.45	1.55	11.87
	EPA	16-0210	.28	2.13	1.48	11.76
	EPA	16-0213	.34	2.52	1.37	12.37
	EPA	16-0218	.34	2.88	1.45	11.67
	EPA	AVERAGE	.31	2.50	1.46	11.92
	Toyo Kogyo	2-1	.204	2.10	1.33	---
	Toyo Kogyo	2-2	.258	1.99	1.26	---
	Toyo Kogyo	2-3	.240	2.20	1.30	---
	Toyo Kogyo	AVERAGE	.234	2.10	1.30	---
1975 Federal Standards			.41	3.40	3.10	---

TABLE II

Toyo Kogyo 1975 Prototypes With Rotary Engines
Steady State Emissions and Fuel Consumption
(idle mode data in grams per minute, all other modes in grams per mile)

Vehicle	Mode	HC	CO	NOx	MPG
50,000-mile car, MCCIII No. 1, RX3, 4-speed, 2750 # inertia	idle	0.00	.362	.016	*
	15 mph	.02	.44	.26	13.8
	30 mph	.01	.31	.35	16.7
	45 mph	0.00	.22	.40	21.2
	60 mph	0.00	.22	.93	20.3
40,000-mile car, MCCIV, No.1, RX4, automatic, 3000# inertia	idle	.002	.016	.026	**
	15 mph	0.00	.02	.19	14.3
	30 mph	.01	.21	.25	16.8
	45 mph	.01	.17	.77	16.8
	60 mph	.01	.20	1.64	17.8

*idle fuel consumption = .633 gallons per hour

**idle fuel consumption = .711 gallons per hour

TABLE III

Toyo Kogyo RX3 Rotary @ 3500# Inertia
(emission data in grams per mile)

	Test Number	HC	CO	NOx	MPG
RX3 with modified secondaries	16-0229	.33	1.88	1.17	11.67
1975 Federal Standards		.41	3.40	3.10	---

TABLE IV

Hot Start 1972 FTP's of RX4 With
Richer Carburetion
(emission data in grams per mile)

Vehicle	Test Number	HC	CO	NOx	MPG
RX4 w/richer carburetion	16-0225	.04	3.56	.48	11.38
	16-0228	.09	7.28	.46	11.33
	AVERAGE	.07	5.42	.47	11.36

Driver's Trace for RX3
at Elevated (3500#) Inertia

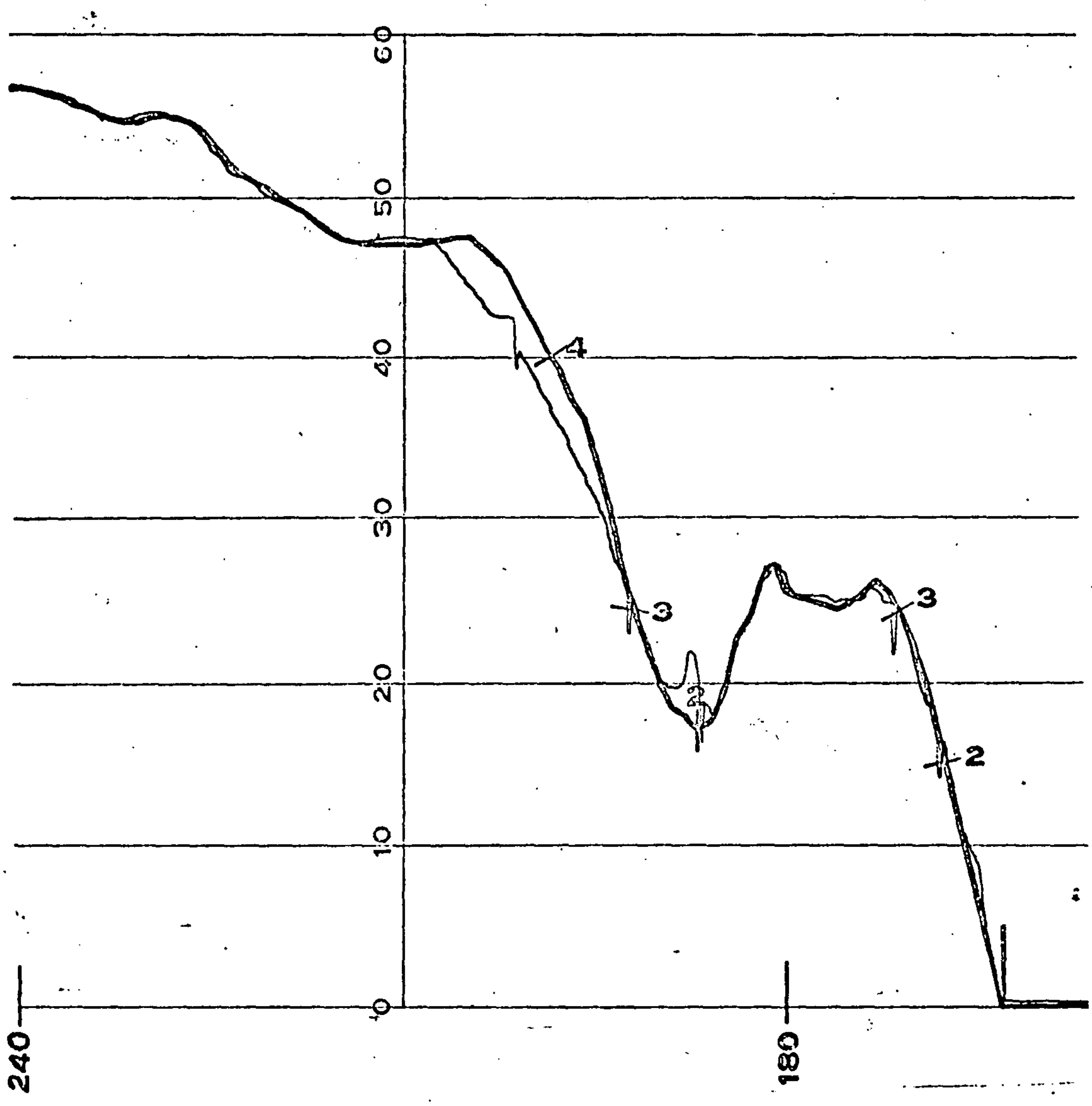

Figure 1.

FEDERAL EMISSION TESTING PROCEDURES FOR LIGHT DUTY VEHICLES

The Federal procedures for emission testing of light duty vehicles involves operating the vehicle on a chassis dynamometer to simulate a 7.5 mile (1972 procedure) or 11.1 mile (1975 procedure) drive through an urban area. The cycle is primarily made up of stop and go driving and includes some operation at speeds up to 57 mph. The average vehicle speed is approximately 20 mph. Both the 1972 and 1975 procedures capture the emissions generated during a "cold start" (12-hour soak @ 68°F to 86°F before start-up). The 1975 procedure also includes a "hot start" after a ten minute shut-down following the first 7.5 miles of driving.

Vehicle exhaust is drawn through a constant volume sampler (CVS) during the test. The CVS dilutes the vehicle's exhaust to a known constant volume with make up air. A continuous sample of the diluted exhaust is pumped into sample bags during the test.

Analysis of the diluted exhaust collected in the sample bags is used to determine the mass of vehicle emissions per mile of operation (grams per mile). A flame ionization detector (FID) is used to measure unburned hydrocarbon (HC) concentrations. Non-dispersive infrared (NDIR) analyzers are used to measure carbon monoxide (CO) and carbon dioxide (CO_2). A chemiluminescence (CL) analyzer is used to determine oxides of nitrogen (NOx) levels.

These procedures are used for all motor vehicles designed primarily for transportation of property and rated at 6,000 pounds GVW or less, or designed primarily for transportation of persons and having a capacity of twelve persons or less. Each new light duty vehicle sold in the United States in model years 1973 and 1974 must emit no more than 3.4 gpm HC, 39. gpm CO and 3.0 gpm NOx when using the 1972 procedure. In 1975 the standards will change to .41 gpm HC. 3.4 gpm CO and 3.1 gpm NOx using the 1975 procedure. In 1976 the standards will be .41 gpm HC, 3.4 gpm CO and .4 gpm NOx using the 1975 procedure.