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A COMPARATIVE STUDY OF THE FUEL ECONOMY CHARACTERISTICS OF MAZDA ROTARY ENGINE VEHICLES VERSUS CONVENTIONAL RECIPROCATING ENGINE VEHICLES

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Test and Evaluation Branch
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Introduction

Because of the widespread public interest in the fuel economy performance of new automobiles available for purchase in the United States, the Environmental Protection Agency published, on September 18, 1973, the fuel economy results of 1974 model year prototype vehicles tested by the EPA in its emission control certification program. The driving cycle utilized in this program is representative of typical city vehicle operation; the driving cycle is 7.5 miles long, and the test begins with a cold start which is representative of typical commuter driving.

The fuel economy data were grouped by the weight class of automobiles, because vehicle weight is the single most important vehicle design factor characterizing fuel economy. Within each weight class, vehicles were listed in order of their fuel economy performance, with the best performers, in terms of highest miles per gallon, listed first.

The data published for the 2750 lb. inertia weight class included a range of fuel economy performance from a high of 24.6 mpg to a low of 10.6 mpg. The lowest fuel economy in the 2750 lb. weight class was achieved by three rotary engine Mazda vehicles: 10.6, 10.8 and 11.0[1] mpg. Exclusive of these three vehicles, the range of fuel economy results in the 2750 lb. class was from 24.6 to 15.1 mpg; in other words, the next lowest performing vehicle in the 2750 lb. weight class achieved 37% better fuel economy than did the best rotary Mazda, while the best performer in the class achieved 124% better fuel economy.

When these data were first published, Washington counsel for Mazda Motors of America informally contacted the EPA to convey the point of view that Mazda Motors of America believed that the fuel economy results of its vehicles were substantially better than that reported by the EPA. EPA invited Mazda Motors to provide data to support the contention that an error had been made in the EPA testing of Mazda vehicles. No such data were presented at that time.

Early in January of 1974, United Press International carried a story datelined Los Angeles which stated that "Mazda Motors of America today accused the Environmental Protection Agency of publishing misleading figures about the fuel consumption of its Wankel-powered cars. Mazda presented a report by J. D. Powers and Associates, a Los Angeles research firm, indicating a majority of owners of the rotary engine Mazda were getting 17 miles per gallon in city driving and 20 miles on the highway."

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[1] The fuel economy for this vehicle was originally reported as 10.7 mpg due to a clerical error.

In response to inquiries on this matter from UPI, EPA explained the basis of its fuel economy testing, and expressed the view that it is confident that the relative fuel economy results on all cars for which EPA has published fuel economy data, including the Mazda rotary, are valid.

Mazda Motors of America, after these newspaper stories, offered in rebuttal a variety of reports and statements from owners to the effect that the fuel economy of its vehicles is higher than that reported by the EPA. EPA technical staff studied these materials, and concluded that they did not invalidate the relative fuel economy results measured by EPA on the Mazda rotary engine car. Even though different absolute miles per gallon results were reported in various studies, as would be expected because of the differing test procedures used, several of these studies commented specifically on the relatively low fuel economy performance of the Mazda rotary engine car (compared to other equivalent weight vehicles).

However, to further investigate Mazda Motors of America's assertion that the Federal Test Procedure, while an adequate test for conventionally-powered cars (including, according to Mazda, its own conventional car), may be inadequate to fairly assess the fuel economy results of rotary engine cars, the EPA invited Mazda to participate with it in a test program. The purpose of this test program was to investigate whether in the case of the rotary engine car the relationship of fuel economy in city driving to highway driving may be different from that relationship for conventionally-powered cars. The hypothesis was that if such a difference exists, it could help to explain the different fuel economy results reported by Mazda and by EPA.

On March 4, 1974, Mazda Motors of America accepted the EPA invitation to conduct a test program that consisted of the following basic approach:

A) EPA would develop a highway driving cycle that would simulate on the chassis dynamometer a typical manner in which vehicles are driven outside of cities.[2]

B) EPA would determine the comparative fuel economy of Mazda and contemporary piston engine vehicles on the newly developed highway driving cycle and the Federal City Driving Cycle.

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[2] EPA technical staff had for several months been working on a highway test cycle with the SAE, and was in any case ready to define a highway test cycle for 1975 model year testing.

C) EPA would conduct such other tests as might help to identify inherent differences between the rotary and piston engine that could further explain the fuel economy differences between the engine types. Essentially, these tests would involve determining hot start versus cold start fuel economy characteristics of the two engine types.

D) Other manufacturers would be invited to supply vehicles powered by conventional piston engines for fuel economy performance comparison with the Mazda rotary engine vehicles.

Background of EPA Fuel Economy Data

The President's Energy Message of April 18, 1973, directed EPA, in cooperation with the Department of Commerce and the Council on Environmental Quality, to develop a voluntary auto fuel labeling program beginning with 1974 model year cars. EPA promptly published the fuel economy results that 1973 model year cars had demonstrated during testing at the EPA laboratory for the purpose of certification that their air pollution emissions were within Federal standards. Under Federal law, cars may not be sold in the U.S. unless they comply with air pollution standards, and thus prototype models of all basic types of cars are tested bv EPA each year. The 1973 fuel economy data were published in the Federal Register; beginning with the 1974 model year, some of the data appeared in dealers' showrooms, and on the car themselves.

All fuel economy testing has its limitations, because fuel economy of any individual vehicle depends on many factors, one of the most important being how the vehicle is driven. The EPA has clearly pointed out in the fuel economy data that it has published that individual drivers can expect to get better or poorer fuel economy on their own cars of the same type as tested by EPA, depending primarily on such factors as the options on the car they buy, number of short and long trips, use in city traffic or at steady speeds, and personal driving habits.

The EPA Federal City Driving Cycle test involves driving the vehicle, on a dynamometer, through a 7.5 mile driving cycle that is typical of city/suburban driving common to urban commuting. The test begins when the vehicle is cold, because a cold start is typical of commuting travel. This test procedure is different from fuel economy test procedures typically used by automakers since automakers test their cars, with engines that are already warmed up, at more or less steady speeds on a test track or on the highway. The EPA test is far more repeatable than a test track or highway fuel economy test, and of course more accurately represents the type of driving of a typical commuter; also, the EPA-published fuel economy data is the only data available on so large a number of different cars that is obtained under strictly controlled, entirely repeatable conditions, and for that reason provides the best basis for comparing the relative fuel economy of cars that are available for purchase bv consumers.

Technical Characteristics of the Mazda Rotary-Powered Vehicle

The combustion chamber configuration of the rotary engine is unusual in that it is extremely elongated in comparison to the conventional reciprocating piston engine. This elongation results in the occurrence of three phenomena that create an unburned hydrocarbon problem for the uncontrolled rotary engine. The first phenomenon, wall quenching, perhaps the most important emission source, results from the quenching or extinguishment of the flame front as it approaches the relatively cool combustion chamber walls. The second phenomenon occuring in the rotary engine is the "crevice effect" which is another quench process that occurs where two relatively cool surfaces enclose an air/fuel mixture at close proximity. In the rotary engine the crevices are formed at the junction of the rotor tip and the housing and in effect represent "dead volume" where combustion does not occur. The third phenomenon "seal leakage" or "blowby" is resultant from the complex sealing required for the rotary. Even a small percentage of unburned mixture can have a large effect on the overall concentration of hydrocarbons. Consequently the uncontrolled rotary engine emits large quantities of hydrocarbon relative to the reciprocating engine.

Fortunately, the high exhaust temperatures of the rotary engine make the rotary conducive to relatively effective exhaust emission control through the use of thermal reactor technology. The achievements of Toyo Kogyo (manufacturers of Mazda) in this area are particularly significant since in past EPA tests Mazda prototype vehicles have demonstrated[3] capability of easily meeting 1975 statutory Federal emission standards (0.41 gm/mi HC, 3.4 gm/mi CO, 3.1 gm/mi NOx). However, the most efficient operation of the thermal reactor occurs with rich air/fuel ratios and fuel economy must be traded-off for emissions control. In short, the rotary engine/thermal reactor combination, while representing an excellent approach for emissions control, is not an optimum combination for fuel economy.

One additional technical characteristic of the Mazda rotary which could affect the reported fuel economy is that oil for lubricating of the apex seals is injected into the combustion chamber. The combustion of this oil could result in lower fuel economy being reported because any measured carbon in the exhaust due to combustion of this oil would be included in the carbon balance calculation. However, the effect of this oil contribution to the fuel economy calculation is less than 1% for the Mazda rotaries. At the typical rotary engine oil consumption rate of one-half to one quart of oil per one thousand miles, the rotary engine vehicles would have consumed 0.001 to 0.002 gallons of oil over the 7.5 mile city driving cycle. Inclusion or exclusion of this oil consumption from the fuel economy calculation would mean a difference of 0.02 to 0.04 miles per gallon, a difference far too small to measure with accuracy.

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[3] Reference EPA test report 73-15, "An Evaluation of Two Toyo Kogyo 1975 Prototypes with Rotary Engines

To address the Mazda Motors assertion that the Federal City Driving Cycle is particularly disadvantageous to the rotary engined vehicle from a fuel economy point of view, EPA also examined the detailed features of the Mazda control system to determine if certain technical characteristics might specifically penalize the Mazda rotary. This evaluation of the Mazda control approach did suggest two control features which may detract from fuel economy during cold start city driving:

1. Like the catalyst system, which will be used on future year cars, the thermal reactor must achieve a minimum operating temperature to be effective for emission control. Consequently, during the cold start phase the trailing spark plug of the Mazda engine is rendered inoperative until the engine coolant reaches about 130°F, at which time the trailing spark plug is activated. This mode of start-up causes the exhaust temperatures to be much hotter thus allowing rapid warm-up of the thermal reactor. Of course, the engine is less efficient during this period of only one spark plug operation, and a fuel economy penalty is incurred. It should be noted, however, that spark advance on conventional engines is often modulated in an analogous fashion to facilitate exhaust emission control during warm-up, and thus the effect on fuel economy of Mazda's approach may not be unique. Nevertheless, it merited further evaluation.

2. During deceleration and idle periods, the thermal reactor could cool down enough to render the thermal reactor inefficient for emission control. To offset this process, the Mazda control system modulates air/fuel mixture and maintains partial throttle during these modes of operation. This characteristic may contribute to losses in fuel economy. However, it should also be noted that this type of control during deceleration is also used in certain electronic fuel injection systems.

<u>Highway Cycle Development</u>

The development of a suitable highway fuel economy test cycle was a project that happened to coincide, in terms of timing, with the need to develop such a test cycle for 1975 model year fuel economy evaluations. A description of that cycle development program has been prepared for this latter purpose. For complete details of that development refer to the EPA Emission Control Technology Division's report "Development of Highway Driving Cycle for Fuel Economy Measurements." A speed versus time analysis of this cycle is presented in the Appendix to this report.

Vehicle Test Fleet

Table I shows the salient features of the vehicles agreed upon between EPA and Mazda Motors of America for use in the test program. All vehicles were obtained from their respective manufacturers. It should be noted that the manufacturers were allowed to supply these vehicles in the best possible state of tune; hence, fuel economy performance was potentially maximized.

TABLE I

Vehicle Characteristics

Make/Model	Engine Family	Carb. (# Carb-# Venturi)	Trans.	Axle Ratio	Inertia Weight Class
Mazda RX2	70 CID/Toyo-3	1-4	4-man.	3.90	2750
Mazda RX3	70 CID/Toyo-3	1-4	3-auto.	3.70	2750
Mazda RX4	80 CID/Toyo-4	1-4	4-man.	3.90	3000
AMC Gremlin	232 CID/IA	1-1	3-man.	2.73	3000
Saab 99EMS[4]	121 CID/BE20	inj.	4-man.	3.89	2750
GM Vega	140 CID/GM 101	1-2	4-man.	2.92	3000
GM Vega	140 CID/GM 101	1-2	3-auto.	2.92	3000
Ford Torino	351 CID w/White	1-2	3-auto.	2.75	4500

The reciprocating engine vehicles were selected to allow varied comparisons with the Mazda rotaries. The Saab represents a small, luxury type vehicle with performance similar to the Mazdas. The Torino in previous EPA testing had demonstrated similar fuel economy to the Mazdas, while being in a substantially higher inertia weight category. The Gremlin and Vega vehicles represent other popular small cars in the Mazda weight class.

Vehicle Testing Program

Each vehicle was subjected to the same test procedure. Cars received in the lab were prepared for testing by draining the fuel and replacing it with Indolene gasoline. (At Mazda's request their vehicles were fueled with unleaded Indolene gasoline while all other vehicles were fueled with 3 gram/gallon leaded Indolene. The request was made to avoid spark plug

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[4] Saab requested and received a recent "running change" for their distributor calibration. EPA approved that change and testing was performed on a vehicle incorporating the recent change. Data both with and without this change is included in the Appendix for comparison.

fouling of the Mazda rotaries and the use of low-lead fuel is recommended in the Mazda Owner's Manual. This difference in fuel was not anticipated to have a significant effect on fuel economy because the manufacturers were permitted to tune the vehicle prior to the test. While no evaporative testing was performed, exhaust emissions tests were conducted on each vehicle as specified in Federal regulations for 1975 and later model year light duty vehicles. After completion of the normal Federal driving cycle the vehicles were allowed to idle for one minute prior to initiation of the highway driving cycle. Additional cooling air was requested by the manufacturers during the highway cycle for the Mazda vehicles and the Saab vehicle to avoid possible engine or control system over-temperature under the limited cooling normally supplied during dynamometer operation.

Fuel economy for each driving cycle was calculated from the measured emissions of hydrocarbon, carbon monoxide and carbon dioxide using a carbon balance technique.[5] For comparative purposes gravimetric analysis of fuel consumption was used for the Mazda and a Vega vehicle, in addition to the carbon balance. The comparison is shown in the Appendix to this report.

It should be noted that with the exception of the Vega vehicles, which were tested only with the additional ten percent horsepower loading specified for air conditioning, all of the vehicles were tested both with and without air conditioning load simulation. While all of the test data are presented in the Appendix, in subsequent sections of this discussion all of the cars will be compared with the additional 10% power absorption to simulate an air conditioning load.

Each vehicle was inspected to assure that the vehicle was calibrated within the tolerances specified by the manufacturers in their 1974 certification application. Additionally, emission results were compared to certification results to verify the validity of the vehicle's emission control performance. This comparison showed that all of the vehicles did meet the 1974 emission standards.

Test Results

Table III presents the ranked average ratio of the highway cycle fuel economy to the Federal test cycle fuel economy. This ratio is called the B/A ratio in the subsequent portions of this report. For the purpose of

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5 This procedure is detailed in "A Report on Automotive Fuel Economy," EPA, OAWP, October 1973.

this table and all subsequent analyses presented, average fuel economy for the two or more tests conducted was calculated using the harmonic mean[6] rather than the arithmetic mean.

TABLE III

Ranked List of Ratio of Highway Cycle Fuel Economy to Federal Cycle B/A Ratio

Vega Manual	1.75
Mazda RX4	1.64
Torino	1.60
Mazda RX2	1.58
Gremlin	1.54
Saab	1.49
Vega Automatic	1.48
Mazda RX3	1.43

A statistical analysis of the data grouped as rotary engines versus reciprocating engines was made to check the hypothesis that is apparent from simple inspection of the data in Table III, i.e., that the mean B/A ratio of each group was statistically the same for the two groups. That analysis, with 99% confidence, did not reject that hypothesis. On the basis of this statistical test, EPA concludes that there is no significant difference between the average B/A ratio of the rotary engine powered Mazdas and the average B/A ratio of the conventional reciprocating engine powered vehicles included in the test program.

Table IV shows the ranked fuel economy for all of the vehicles for both the Federal City Driving Cycle and for the Highway Cycle. While indicating minor juxtiposition between the Federal City and Highway ranked lists, reinforces EPA's judgement that the EPA published fuel economy data is a reasonably valid predictor of overall relative fuel economy performance. This outcome of the test program does not support the argument that the Federal City Test Cycle unfairly ranks the Mazda rotary.

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[6] The following example illustrates the effect of using the harmonic mean rather than the arithmetic mean. Suppose a motorist took a trip of 600 miles and used three tanks of gasoline. For the first 200 mile segment he used 10 gallons, in the second 200 mile segment he used 20 gallons and for the third 200 mile segment he used 18 gallons. The arithmetic mean of the individual fuel economies would be 13.7 mpg - a wrong answer. The trip was 600 miles total using 48 gallons with an economy of 12.5 mpg. The correct answer is obtained by finding the harmonic mean.

TABLE IV

Ranked Fuel Economy

City Driving Cycle		% Lower than Best	Highway Driving Cycle		% Lower than Best
Saab	20.6 mpg	--	Vega, Manual	30.7 mpg	--
Vega, auto	18.7 mpg	9%	Saab	30.6 mpg	0%
Gremlin	17.7 mpg	14%	Vega, auto.	27.7 mpg	10%
Vega, manual	17.5 mpg	15%	Gremlin	27.2 mpg	11%
Mazda RX2	13.4 mpg	35%	Mazda RX2	21.2 mpg	31%
Mazda RX3	13.3 mpg	35%	Mazda RX4	20.5 mpg	33%
Mazda RX4	12.5 mpg	39%	Torino	20.0 mpg	35%
Torino	12.5 mpg	39%	Mazda RX3	19.0 mpg	38%

The "% Lower than Best" columns in Table IV indicate the relative fuel economy performance of the test vehicles in comparison to the best performer tested, e.g. in city driving the Torino and Mazda vehicles got 35 to 39 percent lower fuel economy than the Saab. Interestingly, except for the manual transmission Vega this relative performance is not significantly different for the highway cycle when compared to the city cycle, e.g. the Torino and Mazda vehicles got 31 to 38 percent lower fuel economy than the Saab. This, of course, is attributable to the relative constancy for the B/A ratio for the cars tested.

A comparison, where possible, was made of the cold start city driving fuel economy of the test cars included in this test program, and the fuel economy achieved under the same conditons by prototypes of these vehicles in the 1974 model year certification program. Table V presents these data for the Vega, Mazda and Ford vehicles. Direct comparison of the other vehicles was not possible because comparable certification prototypes were not tested by EPA.

From these data it can be seen that the Mazda vehicles and the Ford Torino demonstrated higher cold start city driving fuel economy in this test program than they did in 1974 certification testing; the Vega vehicles' fuel economy results were within 5% of each other, which is within the test-to-test variation that can be expected.

To explore the reasons for the differences in the fuel economy results of the Mazdas and the Torino, a complete review of both vehicular and test parameters was made. The parameters checked are listed in Table VI. With the single exception of a clerical error on one Mazda test, no discrepancies were found that would account for the differences in fuel economy results[7].

[7] The Mazda vehicles' carburetors were not flow tested. Valid comparison of flow tests results can best be made using the same apparatus and procedures as employed to generate the flow curves submitted during the certification process. In the case of the Mazda vehicles such testing would have had to be performed in Japan. EPA considered this possibility and decided that it was impractical.

TABLE V

Comparison of City Driving (cold start)
Fuel Economy - This Program
vs. 1974 Certification Results

Vehicle	Trans.	Certification EPA	Certification Manufacturer	Fuel Economy Program
Mazda RX2	Manual	10.6 mpg	12.1 mpg	13.4 mpg
Mazda RX3	Auto	11.0*mpg	12.1 mpg	13.3 mpg
Mazda RX4	Manual	10.4 mpg	11.3 mpg	12.5 mpg
Torino	Auto	10.8 mpg	10.4 mpg	12.5 mpg
Vega**	Auto	17.9 mpg	---	18.7 mpg
Vega**	Manual	17.4 mpg	---	17.5 mpg

* Due to a clerical error the results for this vehicle had been previously reported by EPA as 10.7 mpg.

** The same certification prototype tested by EPA for 1974 certification was furnished by General Motors for test in the Rotary/Piston Fuel Economy Program.

TABLE VI

Summary of Parametric Checks

Vehicular Parameters

Ford Torino
- Vacuum hose routing and connections
- Basic ignition timing
- Spark delay valve
- Carburetor number
- Carburetor flow curve (supplied by Ford)
- Choke setting
- Choke lever arm length
- Axle ratio
- Tire size

Mazda Rotary Vehicle
- Distributor calibration
- Control unit and modulating switches
- Carburetor number
- Deceleration and air control valve
- Throttle release
- Idle switch
- Altitude compensator
- Decel valve
- Air control valve
- Air pump and connections
- Axle ratio
- Tire size

Test Parameters

- Dynamometer inertia settings
- Dynamometer horsepower settings
- Dynamometer power absorption calibration
- Constant volume sampler calibration
- CO_2 analytical measurement calibration
- Fuel economy calculation
- Test cell and ambient temperature and barometric pressure

Inasmuch as the Ford and EPA fuel economy tests on the Ford Torino certification prototype vehicle correlated closely, the differences in the results between certification vehicle and the special test program Torino must be attributed to differences in the state of tune of the vehicles (see below for further discussion of this factor).

As regards the Mazda vehicles, for which EPA test results did not correlate closely with results achieved in the Toyo Kogyo lab in Japan, further investigations were made of test data drawn from two other sources: results of end-of-assembly-line vehicles tested by Toyo Kogyo in Japan, and results of new vehicles tested by the California Air Resources Board on new vehicles sampled at ports of entry. These results are listed in Table VII, together with the Toyo Kogyo and EPA certification test results.

A number of observations and conclusions can be made through examination of Table VII:

(1) Laboratory-to-laboratory comparison of equivalent mileage and type vehicle test data shows that the Toyo Kogyo laboratory consistently measures higher fuel economy. The 4000-mile certification data comparison shows Toyo Kogyo measurements to be on the average 10.2% higher than the EPA measurement. Similarly, the assembly line test and California Air Resources Board results show Toyo Kogyo measurements to be on the average 8.9% higher than the California Air Resources Board measurements for zero mileage vehicles.

(2) Comparison of Toyo Kogyo 4000-mile certification data to Toyo Kogyo assembly line test data shows no significant difference in fuel economy (on the average) between zero-mile vehicles and 4000-mile vehicles. In fact, the newly built vehicles show slightly better fuel economy. This is a surprising fact since engine break-in would be expected to reduce engine/drivetrain internal friction, thus causing improvements in fuel economy with break-in. Apparently, such improvements do not occur for the Mazda rotary, or, if they do, are offset by deterioration of tuned condition by the time 4000 miles are accumulated, e.g., lead fouling of spark plugs, which Mazda's owners' manual specifically warns against.

(3) The highest average fuel economy in Table VII, obtained by Toyo Kogyo, was 12.5 mpg for the RX3 manual on the basis of assembly line tests. The Toyo Kogyo 4000-mile certification test of the RX3 manual, which must represent the average calibration, measured a fuel economy of 11.8 mpg. The lowest fuel economy obtained by Toyo Kogyo, as reported in Table VII, was 11.2 mpg for the 4000-mile test of the RX4 automatic. These values are significantly lower than

TABLE VII

Summary of Other Rotary Fuel Economy Data

Vehicle	Data Source	Fuel Economy (mpg)
RX2 manual	4000-mi. cert. (TK Japan)	12.1
	4000-mi. cert. (EPA)	10.6
	Zero-mile (TK Japan)	not available
	Zero-mile (California)	12.1
RX3 manual	4000-mi. cert. (TK Japan)	11.8
	4000-mi. cert. (EPA)	10.8
	Zero-mile (TK Japan)(2)	12.5
	Zero-mile (California)(1)	11.7
RX3 automatic	4000-mi. cert. (TK Japan)	12.1
	4000-mi. cert. (EPA)	11.0
	Zero-mile (TK Japan)(3)	12.2
	Zero-mile (California)(1)	11.0
RX4 manual	4000-mi. cert. (TK Japan)	11.3
	4000-mi. cert. (EPA)	10.4
	Zero-mile (TK Japan)(4)	11.8
	Zero-mile (California)(1)	not available
RX4 automatic	4000-mi. cert. (TK Japan)	11.2
	4000-mi. cert. (EPA)	10.3
	Zero-mile (TK Japan)	not available
	Zero-mile (California)	not available

(1) California Air Resources Board test on port-of-entry new vehicle sample - average of three tests on 1 car.

(2) Assembly line tests by Toyo Kogyo in Japan - average of 22 cars tested in January and February 1974.

(3) Assembly line tests by Toyo Kogyo in Japan - average of 15 cars tested in January and February 1974.

(4) Assembly line tests by Toyo Kogyo in Japan - average of 50 cars tested in January and February 1974.

the values obtained by EPA in the current test program. This suggests that the vehicles currently tested by EPA represented the exceptional Mazda vehicle rather than an average vehicle.

In view of the above considerations only one plausible explanation for the differences among test program results for the Ford and Mazda vehicles remains. Since the test program was voluntary and to insure equal treatment for all manufacturers, each manufacturer was encouraged by EPA to deliver his test cars to EPA in the best possible state of tune-up. It is reasonable to assume that Mazda, which requested the conduct of the special test program, took full advantage of this opportunity to present the fuel economy of its cars in the most favorable light. A similar assumption can be made for the other manufacturers' vehicles. This means that the state of tune of the cars in this test program is likely to have been better than the state of tune of the cars after 4000 miles in the certification program, since tune-up or maintenance are not allowed at any point during the 4000-mile mileage accumulation or prior to the 4000-mile certification test.

As regards the Vega vehicles, for which city-driving cold-start fuel economy correlated closely with fuel economy data generated last year, this is explainable by the fact that General Motors furnished for the special test program exactly the same vehicles that it used to demonstrate compliance with emission standards in last year's certification program. General Motors, as a matter of policy, retains these vehicles; no other manufacturer furnished exactly the same vehicles for the special test program.

Further, the Mazda certification vehicles accumulated mileage with leaded fuel and were tested with leaded fuel. The Mazda vehicles in this program were, at Mazda's request, permitted to be tested with lead-sterile fuel, since the EPA engineers had concluded that use of such fuel would make no difference to fuel economy if tune-up was permissible prior to the test (i.e., change of plugs, etc.). However, plug fouling with leaded fuels has been reported to be a problem with rotary engines in the past, which is one reason why the Mazda owner's manual contains a recommendation to use low lead fuel. Mazda's 4000-mile 1974 certification vehicles had, in accordance with their applicable regulations, accumulated their 4000 miles with fully leaded gasoline.

In addition to the preceeding comparisons, EPA analyzed the relative fuel economy performance under cold start conditions and hot start conditions for the test vehicles. To do this the fuel economy of each vehicle was calculated for a hot start Federal City Driving Cycle (sample bags 2 and 3 of the 1975 Federal Test Procedure) and compared to the cold start Federal City Driving Cycle (sample bags 1 and 2 of the 1975 Federal Test Procedure). Table VIII indicates the results of that analysis.

TABLE VIII

Ratio of Hot Start Fuel Economy to Cold Start Fuel Economy

Mazda RX2	1.09
Mazda RX3	1.12
Mazda RX4	1.11
Vega manual	1.09
Vega automatic	1.12
Gremlin	1.10
Torino	1.11
Saab	1.08

The data in Table VIII do not indicate that the rotary-powered vehicle suffers or benefits any more from a cold start test than does a typical reciprocating engine-powered vehicle.

Conclusions

1. The relationship of fuel economy results obtained by comparing vehicle operation on the highway driving cycle to cold start vehicle operation on the Federal City Driving Cycle is about the same for the rotary engine Mazda as it is for conventional piston engine vehicles, i.e., highway driving results in about 50% better fuel economy than does cold start city driving.

2. On both the highway cycle and city cycle, the three Mazda rotary vehicles and the Ford Torino, a significantly heavier car, demonstrated similar fuel economy performance that is considerably lower than that demonstrated by the other vehicles in the test program that are in about the same weight class as the Mazda.

3. No significant differences between the relative hot start and cold start fuel economy were found by comparing the Mazda rotary vehicles to the conventional reciprocating piston engine vehicles tested in the program.

4. The state of tune is an important consideration when testing vehicles for fuel economy, because the state of tune significantly affects the performance of vehicles. The differences in fuel economy found between the Mazda and Ford Torino certification and special fuel economy test vehicles was attributed to this effect as checks of vehicular and test parameters indicated no other differences. This difference between the Mazda and Ford Torino fuel economy results could be anticipated and is acceptable as all manufacturers were recommended to bring the test vehicles to the EPA lab in the best possible state of tune.

A P P E N D I X

Appendix A
Highway Cycle - Speed vs. Time

Appendix B
Comparison of Fuel Economy - Gravimetric Analysis vs. Carbon Balance

Appendix C
Emission and Fuel Economy Data

APPENDIX A

***** EPA HIGHWAY FUEL ECONOMY DRIVING CYCLE *****
*** SPEED (MPH) VS TIME (SEC) ***

Sec.	MPH	Sec.	MPH	Sec.	MPH	Sec.	MPH	Sec.	MPH	Sec.	MPH	Sec.	MPH	Sec.	MPH
0	0.0	50	41.4	100	49.1	150	44.7	200	43.0	250	48.2	300	40.2	350	58.4
1	4.7	51	42.2	101	49.1	151	44.9	201	43.0	251	48.2	301	41.1	351	58.2
2	9.6	52	42.9	102	49.0	152	45.2	202	43.1	252	48.1	302	41.8	352	58.1
3	14.5	53	43.5	103	49.0	153	45.7	203	43.4	253	48.6	303	42.4	353	58.0
4	17.4	54	44.0	104	49.1	154	45.9	204	43.9	254	48.9	304	42.8	354	57.9
5	19.8	55	44.3	105	49.2	155	46.3	205	44.0	255	49.1	305	43.3	355	57.6
6	21.8	56	44.5	106	49.3	156	46.8	206	43.5	256	49.1	306	43.8	356	57.4
7	24.0	57	44.8	107	49.4	157	46.9	207	42.6	257	49.1	307	44.3	357	57.2
8	25.8	58	44.9	108	49.5	158	47.0	208	41.5	258	49.1	308	44.7	358	57.1
9	27.1	59	45.0	109	49.5	159	47.1	209	40.7	259	49.1	309	45.0	359	57.0
10	28.0	60	45.1	110	49.5	160	47.6	210	40.0	260	49.0	310	45.2	360	57.0
11	29.0	61	45.4	111	49.4	161	47.9	211	40.0	261	48.9	311	45.4	361	56.9
12	30.0	62	45.7	112	49.1	162	48.0	212	40.3	262	48.2	312	45.5	362	56.9
13	30.7	63	46.0	113	48.9	163	48.0	213	41.0	263	47.7	313	45.8	363	56.9
14	31.5	64	46.3	114	48.6	164	47.9	214	42.0	264	47.5	314	46.0	364	57.0
15	32.2	65	46.5	115	48.4	165	47.8	215	42.7	265	47.2	315	46.1	365	57.0
16	32.9	66	46.8	116	48.1	166	47.3	216	43.1	266	46.7	316	46.5	366	57.0
17	33.5	67	46.9	117	47.7	167	46.7	217	43.2	267	46.2	317	46.8	367	57.0
18	34.1	68	47.0	118	47.4	168	46.2	218	43.4	268	46.0	318	47.1	368	57.0
19	34.6	69	47.1	119	47.3	169	45.9	219	43.9	269	45.8	319	47.7	369	57.0
20	34.9	70	47.2	120	47.5	170	45.7	220	44.3	270	45.6	320	48.3	370	57.0
21	35.1	71	47.3	121	47.8	171	45.5	221	44.7	271	45.4	321	49.0	371	57.0
22	35.7	72	47.2	122	47.9	172	45.4	222	45.1	272	45.2	322	49.7	372	57.0
23	35.9	73	47.1	123	48.0	173	45.3	223	45.4	273	45.0	323	50.3	373	56.9
24	35.8	74	47.0	124	47.9	174	45.0	224	45.8	274	44.7	324	51.0	374	56.8
25	35.3	75	46.9	125	47.9	175	44.0	225	46.5	275	44.5	325	51.7	375	56.5
26	34.9	76	46.9	126	47.9	176	43.1	226	46.9	276	44.2	326	52.4	376	56.2
27	34.5	77	46.9	127	48.0	177	42.2	227	47.2	277	43.5	327	53.1	377	56.0
28	34.6	78	47.0	128	48.0	178	41.5	228	47.4	278	42.8	328	53.8	378	56.0
29	34.8	79	47.1	129	48.0	179	41.5	229	47.3	279	42.0	329	54.5	379	56.0
30	35.1	80	47.1	130	47.9	180	42.1	230	47.3	280	40.1	330	55.2	380	56.1
31	35.7	81	47.2	131	47.3	181	42.9	231	47.2	281	38.6	331	55.8	381	56.4
32	36.1	82	47.1	132	46.0	182	43.5	232	47.2	282	37.5	332	56.4	382	56.7
33	36.2	83	47.0	133	43.3	183	43.9	233	47.2	283	35.8	333	56.9	383	56.9
34	36.5	84	46.9	134	41.2	184	43.6	234	47.1	284	34.7	334	57.0	384	57.1
35	36.7	85	46.5	135	39.5	185	43.3	235	47.0	285	34.0	335	57.1	385	57.3
36	36.9	86	46.3	136	39.2	186	43.0	236	47.0	286	33.3	336	57.3	386	57.4
37	37.0	87	46.2	137	39.0	187	43.1	237	46.9	287	32.5	337	57.6	387	57.4
38	37.0	88	46.3	138	39.0	188	43.4	238	46.8	288	31.7	338	57.8	388	57.2
39	37.0	89	46.5	139	39.1	189	43.9	239	46.9	289	30.6	339	58.0	389	57.0
40	37.0	90	46.9	140	39.5	190	44.3	240	47.0	290	29.6	340	58.1	390	56.9
41	37.0	91	47.1	141	40.1	191	44.6	241	47.2	291	28.8	341	58.4	391	56.6
42	37.0	92	47.4	142	41.0	192	44.9	242	47.5	292	28.4	342	58.7	392	56.3
43	37.1	93	47.7	143	42.0	193	44.8	243	47.9	293	28.6	343	58.8	393	56.1
44	37.3	94	48.0	144	43.1	194	44.4	244	48.0	294	29.5	344	58.9	394	56.4
45	37.8	95	48.2	145	43.7	195	43.9	245	48.0	295	31.4	345	59.0	395	56.7
46	38.6	96	48.5	146	44.1	196	43.4	246	48.0	296	33.4	346	59.0	396	57.1
47	39.3	97	48.8	147	44.3	197	43.2	247	48.0	297	35.6	347	58.9	397	57.5
48	40.0	98	49.1	148	44.4	198	43.2	248	48.0	298	37.5	348	58.8	398	57.8
49	40.7	99	49.2	149	44.6	199	43.1	249	48.1	299	39.1	349	58.6	399	58.0

NOTE: 3 seconds and 2 seconds of idle are added at the beginning and end of the cycle respectively.

APPENDIX A (con't.)

Sec.	MPH	Sec.	MPH	Sec.	MPH	Sec.	MPH	Sec.	MPH	Sec.	MPH	Sec.	MPH	Sec.	MPH
400	58.0	450	58.0	500	54.3	550	55.1	600	47.7	650	52.2	700	55.5	750	15.1
401	58.0	451	58.0	501	54.2	551	55.0	601	47.9	651	52.5	701	55.9	751	12.4
402	58.0	452	58.0	502	54.1	552	54.9	602	48.3	652	52.1	702	56.1	752	9.7
403	58.0	453	58.0	503	54.1	553	54.6	603	49.0	653	51.6	703	56.3	753	7.0
404	58.0	454	57.9	504	54.1	554	54.4	604	49.1	654	51.1	704	56.4	754	5.0
405	57.9	455	57.9	505	54.0	555	54.2	605	49.0	655	51.0	705	56.5	755	3.3
406	57.8	456	58.0	506	54.0	556	54.1	606	48.9	656	51.0	706	56.7	756	2.0
407	57.7	457	58.1	507	54.0	557	53.8	607	48.0	657	51.1	707	56.9	757	0.7
408	57.7	458	58.1	508	54.0	558	53.4	608	47.1	658	51.4	708	57.0	758	0.0
409	57.8	459	58.2	509	54.0	559	53.3	609	46.2	659	51.7	709	57.3		
410	57.9	460	58.3	510	54.0	560	53.1	610	46.1	660	52.0	710	57.7		
411	58.0	461	58.3	511	54.0	561	52.9	611	46.1	661	52.2	711	58.2		
412	58.1	462	58.3	512	54.0	562	52.6	612	46.2	662	52.5	712	58.8		
413	58.4	463	58.2	513	54.1	563	52.4	613	46.9	663	52.8	713	59.1		
414	58.9	464	58.1	514	54.2	564	52.2	614	47.8	664	52.7	714	59.2		
415	59.1	465	58.0	515	54.5	565	52.1	615	49.0	665	52.6	715	59.1		
416	59.4	466	57.8	516	54.8	566	52.0	616	49.7	666	52.3	716	58.8		
417	59.8	467	57.5	517	54.9	567	52.0	617	50.6	667	52.3	717	58.5		
418	59.9	468	57.1	518	55.0	568	52.0	618	51.5	668	52.4	718	58.1		
419	59.9	469	57.0	519	55.1	569	52.0	619	52.2	669	52.5	719	57.7		
420	59.8	470	56.6	520	55.2	570	52.1	620	52.7	670	52.7	720	57.3		
421	59.6	471	56.1	521	55.2	571	52.0	621	53.0	671	52.7	721	57.1		
422	59.4	472	56.0	522	55.3	572	52.0	622	53.6	672	52.4	722	56.8		
423	59.2	473	55.8	523	55.4	573	51.9	623	54.0	673	52.1	723	56.5		
424	59.1	474	55.5	524	55.5	574	51.6	624	54.1	674	51.7	724	56.2		
425	59.0	475	55.2	525	55.6	575	51.4	625	54.4	675	51.1	725	55.5		
426	58.9	476	55.1	526	55.7	576	51.1	626	54.7	676	50.5	726	54.6		
427	58.7	477	55.0	527	55.8	577	50.7	627	55.1	677	50.1	727	54.1		
428	58.6	478	54.9	528	55.9	578	50.3	628	55.4	678	49.8	728	53.7		
429	58.5	479	54.9	529	56.0	579	49.8	629	55.4	679	49.7	729	53.2		
430	58.4	480	54.9	530	56.0	580	49.3	630	55.0	680	49.6	730	52.9		
431	58.4	481	54.9	531	56.0	581	48.7	631	54.5	681	49.5	731	52.5		
432	58.3	482	54.9	532	56.0	582	48.2	632	53.6	682	49.5	732	52.0		
433	58.2	483	54.9	533	56.0	583	48.1	633	52.5	683	49.7	733	51.3		
434	58.1	484	55.0	534	56.0	584	48.0	634	50.2	684	50.0	734	50.5		
435	58.0	485	55.0	535	56.0	585	48.0	635	48.2	685	50.2	735	49.5		
436	57.9	486	55.0	536	56.0	586	48.1	636	46.5	686	50.6	736	48.5		
437	57.9	487	55.0	537	56.0	587	48.4	637	46.2	687	51.1	737	47.6		
438	57.9	488	55.0	538	56.0	588	48.9	638	46.0	688	51.6	738	46.8		
439	57.9	489	55.0	539	56.0	589	49.0	639	46.0	689	51.9	739	45.6		
440	57.9	490	55.1	540	56.0	590	49.1	640	46.3	690	52.0	740	44.2		
441	58.0	491	55.1	541	56.0	591	49.1	641	46.8	691	52.1	741	42.5		
442	58.1	492	55.0	542	56.0	592	49.0	642	47.5	692	52.4	742	40.2		
443	58.1	493	54.9	543	55.9	593	49.0	643	48.2	693	52.9	743	36.7		
444	58.2	494	54.9	544	55.9	594	48.9	644	48.8	694	53.3	744	32.0		
445	58.2	495	54.8	545	55.9	595	48.6	645	49.5	695	53.7	745	28.0		
446	58.2	496	54.7	546	55.8	596	48.3	646	50.2	696	54.2	746	24.5		
447	58.1	497	54.6	547	55.6	597	48.0	647	50.7	697	54.5	747	21.5		
448	58.0	498	54.4	548	55.4	598	47.9	648	51.1	698	54.8	748	19.5		
449	58.0	499	54.3	549	55.2	599	47.8	649	51.7	699	55.0	749	17.4		

Appendix B

Fuel Weigh vs. Carbon Balance Fuel Economy

Vehicle	Configuration	Fuel Weigh '72 FTP	Fuel Weigh Highway	Carbon Balance '72 FTP	Carbon Balance Highway
RX2	without AC	12.8	20.8	13.8	21.4
RX2	with AC	12.4	21.4	13.2	21.3
RX2	with AC	12.3	20.6	13.6	21.0
RX3	without AC	12.3	19.1	13.7	19.7
RX3	with AC	12.3	18.5	13.3	19.0
RX3	with AC	12.5	17.5	13.2	19.0
RX4	without AC	11.7	20.1	12.8	20.5
RX4	with AC	12.5	20.3	12.6	20.8
RX4	with AC	12.6	20.1	12.4	20.2
Vega Auto	with AC	17.8	27.0	18.6	27.6

APPENDIX C

Emission and Fuel Economy Data

Test	Date	Vehicle	Trns.	Conf.	'75 FTP					'72-'74 FTP					Highway Cycle				
					HC	CO	CO_2	NOx	MPG	HC	CO	CO_2	NOx	MPG	HC	CO	CO_2	NOx	MPG
9-329	3-12	99 EMS	M4	w/AC	1.73	25.35	407.20	1.39	19.6	2.03	29.67	423.42	1.36	18.6	0.34	5.81	317.27	1.98	27.1
9-330	3-12	Gremlin	M3	w/AC	1.47	21.50	448.61	2.15	18.2	1.60	25.59	464.78	2.24	17.4	0.49	2.75	319.08	3.49	27.3
9-331	3-12	Torino	A3	w/AC	2.41	15.40	643.67	3.17	13.1	2.64	22.48	670.37	3.16	12.4	1.62	6.48	466.85	4.63	18.4
9-344	3-14	99 EMS	M4	w/AC	1.77	20.24	376.90	1.79	21.4	2.00	24.11	385.38	1.74	20.7	0.54	5.46	279.94	2.66	30.6
9-350	3-15	99 EMS	M4	w/AC	1.92	21.45	376.91	1.85	21.3	2.23	26.07	387.13	1.79	20.4	0.56	5.85	279.55	2.51	30.5
21-18	3-15	Gremlin	M3	wo/AC	1.52	20.84	427.33	1.84	19.1	1.84	26.45	435.89	1.88	18.4	0.48	2.25	309.80	2.76	28.2
21-19	3-05	Torino	A3	wo/AC	2.53	18.86	649.36	3.06	12.9	2.84	28.58	668.47	2.98	12.3	1.62	7.95	452.87	4.53	18.9
21-20	3-06	Gremlin	M3	wo/AC	1.55	19.92	431.75	1.74	19.0	1.72	24.51	441.49	1.79	18.3	0.51	2.86	312.77	2.81	27.8
21-21	3-06	Torino	A3	wo/AC	2.50	17.58	664.58	3.19	12.7	2.74	25.26	682.66	3.06	12.1	1.68	7.52	471.27	4.64	18.2
21-22	3-06	RX3	A3	wo/AC	1.97	17.37	579.94	1.01	14.5	2.02	16.24	614.52	1.06	13.7	0.12	2.16	446.99	0.91	19.7
21-23	3-06	RX2	M4	wo/AC	1.83	14.73	604.25	1.03	14.0	2.12	15.12	612.10	1.08	13.8	0.09	1.96	411.87	1.05	21.4
21-24	3-06	RX4	M4	wo/AC	1.97	13.13	646.95	1.07	13.2	2.07	12.89	668.82	1.04	12.8	0.25	4.08	426.28	1.08	20.5
21-25	3-07	Vega	A3	w/AC	1.48	20.25	407.56	2.53	20.0	1.67	26.70	427.90	2.67	18.7	0.76	2.96	312.18	2.89	27.8
21-26	3-07	Vega	M4	w/AC	1.89	20.06	458.52	1.85	17.9	2.23	26.69	462.88	1.86	17.3	0.63	3.10	284.78	2.62	30.4
21-27	3-07	RX4	M4	w/AC	2.25	10.67	659.17	1.18	13.0	2.33	9.27	682.13	1.18	12.6	0.25	5.69	417.09	1.18	20.8
21-28	3-07	RX2	M4	w/AC	1.61	13.04	622.78	1.00	13.7	2.01	13.91	645.99	0.99	13.2	0.09	1.94	412.30	1.07	21.3
21-29	3-07	RX3	A3	w/AC	1.76	15.57	595.31	1.06	14.2	1.93	15.10	635.85	1.12	13.3	0.16	2.31	462.20	1.03	19.0
21-30	3-08	99 EMS	M4	wo/AC	1.63	24.30	410.74	1.30	19.5	2.02	29.28	423.79	1.25	18.6	0.30	5.06	307.96	1.80	28.0
21-31	3-08	Torino	A3	w/AC	2.25	15.70	641.02	2.92	13.2	2.52	22.95	663.00	2.87	12.5	1.27	5.16	396.57	3.84	21.7
21-32	3-08	RX4	M4	w/AC	2.07	10.63	651.05	1.19	13.2	2.28	9.86	691.39	1.18	12.4	0.36	6.13	427.44	1.30	20.2
21-33	3-08	RX2	M4	w/AC	1.77	12.30	601.56	1.01	14.2	2.12	13.19	624.84	1.02	13.6	0.08	1.10	419.95	1.10	21.0
21-35	3-09	99 EMS	M4	wo/AC	1.71	24.99	409.25	1.37	19.5	2.05	29.72	427.50	1.34	18.5	0.34	6.00	300.58	1.74	28.5
21-37	3-09	RX3	A3	w/AC	1.56	15.18	599.14	1.12	14.1	1.81	15.14	640.39	1.18	13.2	0.11	2.15	463.60	1.05	19.0
21-38	3-09	Vega	A3	w/AC	1.58	21.86	411.74	2.64	19.7	1.96	28.72	425.89	2.69	18.6	0.82	3.47	312.95	3.08	27.6
21-40	3-10	Vega	M4	w/AC	2.39	16.51	443.09	1.77	18.6	2.51	21.52	442.97	1.78	18.3	0.71	2.63	284.91	2.64	30.5
21-42	3-13	Gremlin	M3	w/AC	1.41	17.62	439.70	1.94	18.8	1.51	22.30	453.09	2.04	18.0	0.47	5.34	318.54	3.31	27.0
21-43	3-13	Vega	M4	w/AC	2.38	15.89	447.22	1.81	18.5	2.48	21.21	460.24	1.85	17.7	0.70	2.60	280.35	2.59	31.0
21-45	3-13	99 EMS	M4	w/AC	1.54	22.87	416.51	1.53	19.4	1.84	27.64	431.68	1.49	18.4	0.28	4.66	308.96	2.09	28.0