An Evaluation of Three Honda Compound Vortex Controlled Combustion (CVCC) Powered Vehicles

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Background

This fall the Honda Motor Company of Japan announced publicly that they had developed an engine featuring Compound Vortex Controlled Combustion (CVCC), which would meet the Federal emission requirements for model year 1975 without after-treatment devices such as thermal reactors or catalysts. Honda also submitted a detailed report of their testing program on this engine to EPA as part of their annual status report. To confirm what appeared to be a substantial breakthrough in emission control technology, EPA contacted the Honda Motor Company and offered to conduct confirmatory tests on a vehicle in the Ann Arbor laboratory. Honda accepted the EPA offer and delivered three vehicles for test on December 6, 1972.

Vehicles Tested

All three of the vehicles supplied by Honda were equipped with essentially the same version of the Compound Vortex Controlled Combustion (CVCC) engine. Minor differences included the manufacturing processes used (sand vs. die casting) and differences in control linkages. Each engine was a water cooled in-line four cylinder with an overhead cam. Displacement was 1,948 cc (119 CID). Manufacturer rated maximum horsepower was 65 (DIN) @ 5000 rpm.

The CVCC engine burns a heterogeneous air-fuel mixture. In concept it is similar in some respects to the more well-known stratified charge engines of Ford (PROCO) and Texaco (TCCS). While the Ford and Texaco engines use direct cylinder fuel injection to obtain charge stratification, the Honda CVCC engine obtains stratification with the use of a prechamber.

Two separate intake valves are used on each cylinder of the CVCC engine. One valve is located in the prechamber and the other in the main chamber. The smallest venturi of the three barrel carburetor used on the engine supplies a rich mixture to each prechamber. The other two venturis supply the engines main chambers with a very lean mixture. Combustion is initiated in the prechambers with a conventional ignition system and spark plugs (one plug per prechamber). As the burning gases expand from the prechamber, they ignite and burn the lean mixture present in the main chamber. A drawing of the engine and a schematic of the combustion system appears in Figure 1.

The overall air-fuel ratio of the CVCC engine is significantly leaner than stoichiometric. Conventional engines cannot be operated as lean because of the difficulty in igniting mixtures leaner than about 18:1 A/F. Ignition is easily achieved in the CVCC engine by locating the spark plug in the fuel rich prechamber. This very lean overall operation is conducive to low CO emissions because the high availability of oxygen facilitates the conversion of CO to CO_2. The turbulent, oxygen rich, high temperature operation of the main chamber is essential in controlling HC emissions.

NOx formation is a function of air (N_2+O_2) availability and temperature. A significant portion of the combustion in the engine occurs in the very rich region of the prechamber where the air availability is low. By the time the combustion has progressed to the main chamber, where there is high air availability, the temperature has dropped because of expansion.

The vehicles tested were the new Honda "Civic's", a larger model not yet imported into the U.S. The Civic weighs about 1600 pounds and will carry four passengers. The test weight required for emission testing is 2000 pounds. These cars have front wheel drive and all three tested by EPA were equipped with four-speed manual transmissions.

Two of the vehicles had only about 1500 miles on them at the time of the EPA testing. The third vehicle had completed a 50,000-mile durability run using the AMA mileage accumulation schedule. Several components of the engine in the 50,000-mile car were updated to a "production" configuration at the 44,000-mile point of the durability test. Modifications consisted of minor changes to the manifolding and the linkage, dashpot and choke of the carburetor. These changes did not affect the emission levels. All three vehicles were run on lead free fuel (.03 gpg) during the emission testing and the mileage accumulation. The CVCC engine does not require lead free fuel, but Honda ran the durability on .03 grams per gallon lead to determine the durability of the valve train should the use of unleaded fuels be mandatory in the future. The vehicles were not equipped with any "add-on" type control systems such as catalysts, thermal reactors, air injection, or exhaust gas recirculation (EGR) systems.

Test Program

Three different types of emission tests were performed during the evaluation:

1. 1975 Federal Test Procedure (FTP) @2000 pound test weight.

2. Hot start 1972, 2-bag FTP @3000 pound test weight.

3. Steady state tests @ idle, 15, 30, 45 & 60 mph.

The 1975 FTP was used to determine gaseous emissions, particulate emissions, and fuel economy at the vehicle's standard test weight of 2000 pounds. Testing for HC, CO, CO_2, NOx, and aldehydes was done in the Ann Arbor laboratory. Particulate testing was done at Dow Chemical in Midland, Michigan.

Particulate levels were also determined using the hot start 1972 FTP as were the HC, CO, CO_2, and NOx levels. One of the hot start tests was run at the 3000 pound test weight to determine the influence of vehicle weight on exhaust emissions and fuel economy with the CVCC engine.

Gaseous emissions (HC, CO, CO_2, and NOx) and fuel economy were determined during steady state operation at idle, 15, 30, 45, and 60 mph. Particulates were measured at 60 mph.

The Dow particulate procedure simulates an air quench of the vehicle's exhaust gas by routing the exhaust into a 15 7/8 inch diameter tube where it is diluted to a 500 cfm flow. Twenty-seven feet downstream of the tailpipe samples are pulled from the diluted exhaust through fiberglass filters, millepore filters and an Anderson Impactor. While the Dow procedure is not an "official" or standard particulate test, it does allow us to compare particulate emission levels from different vehicles using a common procedure.

A description of the Federal Test Procedure for exhaust emission testing is enclosed (Attachment I).

Test Results

Results are summarized in Tables I, II, III, and IV. Table I lists the results on the 1975 Federal Test Procedure for all three vehicles. The first test (not reported) on the low mileage car #3652 was aborted due to a binding choke linkage which was immediately repaired. All other tests on all three vehicles met the levels required for 1975 easily. NOx levels were less than one-third the 1975 requirement. About a 50% further reduction in NOx would be required for 1976 NOx levels, but it should be noted that EGR was not used on these vehicles. Honda representatives made it clear that the three cars supplied to EPA were 1975 model year prototypes only, with no modifications to improve NOx emissions.

The fuel economy over the LA4 (Federal) driving cycle has been calculated for each test using the carbon balance technique. Actual fuel weights were taken once on both the 50,000-mile vehicle and the low mileage vehicle #3652. The correlation with the carbon balance data indicated there were no significant leaks in the system. Results are listed for fuel economy using both the 1975 (11.1 miles) procedure and the 1972 (7.5 miles) procedure. This was easily accomplished since the first two bags of the 1975 procedure are equivalent to the 1972 procedure. The fuel economy calculated for the 1972 procedure was compared to the values calculated for vehicles tested by EPA during our certification and surveillance programs. The average 1972 FTP fuel economy of the Honda vehicles tested (20.4 mpg) was 20% lower than the average of the 2000 pound 1973 certification vehicles tested by EPA this year (25.5 mpg). Honda data comparing the CVCC powered Civic to the standard Civic with a conventional engine also showed some fuel economy penalty with the CVCC version but only about 10%. Part of this penalty may be due to the fact that Honda vehicles tested had a relatively high power to weight ratio.

The fuel economy results listed on Table II indicate that the fuel economy during the testing at 3000 pounds compared favorably to both the average 3000 pound 1973 certification vehicles and the 3000 pound pre-controlled vehicles of the 1967 model year. At the 3000 pound test weight, the vehicle still had adequate power to keep up with all of the accelerations of the LA4 driving cycle.

The emissions results listed on Table II were derived from a hot start 1972 2-bag test of the low mileage vehicle #3652. An average bag 1/bag 3 ratio for each constituent of the exhaust (HC, CO, CO_2, and NOx) was determined from all the 1975 tests run on this vehicle. These ratios were multiplied by the grams of emissions measured during bag 1 of the hot start test to estimate what a cold start bag 1 would have been. The result is called "bag 1 (calculated)". Used in combination with the two bags of the hot start 1972 test, a "calculated composite" for a cold start 1975 test was determined.

Table III summarizes the results of the steady state testing. HC and CO emissions decreased as speed increased while NOx tended to increase. Emissions in every mode were very low as would be expected from a vehicle that has inherently low emissions and does not require modulation of emission control devices to attain desired driveability and fuel economy objectives.

Table IV summarizes the particulate testing results. Results obtained on three other vehicles using conventional engines are shown for comparison. The data indicates that the particulate emissions from the Honda vehicle are essentially the same as from conventional engines using equivalent fuels.

Although not reported in the Tables, the low mileage 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 with the procedure used. The CVCC exhaust aldehyde level is much lower than the conventional engine, apparently less than .01 grams per mile.

The driveability of the CVCC powered vehicles was evaluated on the road and there were no problems encountered. The engine was very responsive and the acceleration was very strong. Honda reported quarter-mile acceleration times of 17.8 seconds. The vehicles easily maintained expressway speeds with adequate passing power in reserve.

Conclusions

1. All three Honda CVCC vehicles tested repeatedly met the emission levels required for 1975. The lowest emitter of the three had completed the 50,000-mile AMA durability run without incident.

2. There does not appear to be a significant fuel economy or driveability penalty associated with the engine.

3. There is apparently adequate cushion in the emission levels at the 2000-pound test weight to also meet the 1975 levels with a 50% heavier vehicle.

4. There is no particulate emission or smoke problem associated with the CVCC engine.

5. There is no aldehyde emission problem associated with the CVCC engine.

6. Additional NOx control will be required to reach the 1976 levels but the vehicles tested did not employ devices or special calibration for NOx control.

7. The CVCC engine achieved lower emission levels than any other gasoline fueled engine without after-treatment ever tested by EPA.

HONDA CVCC ENGINE

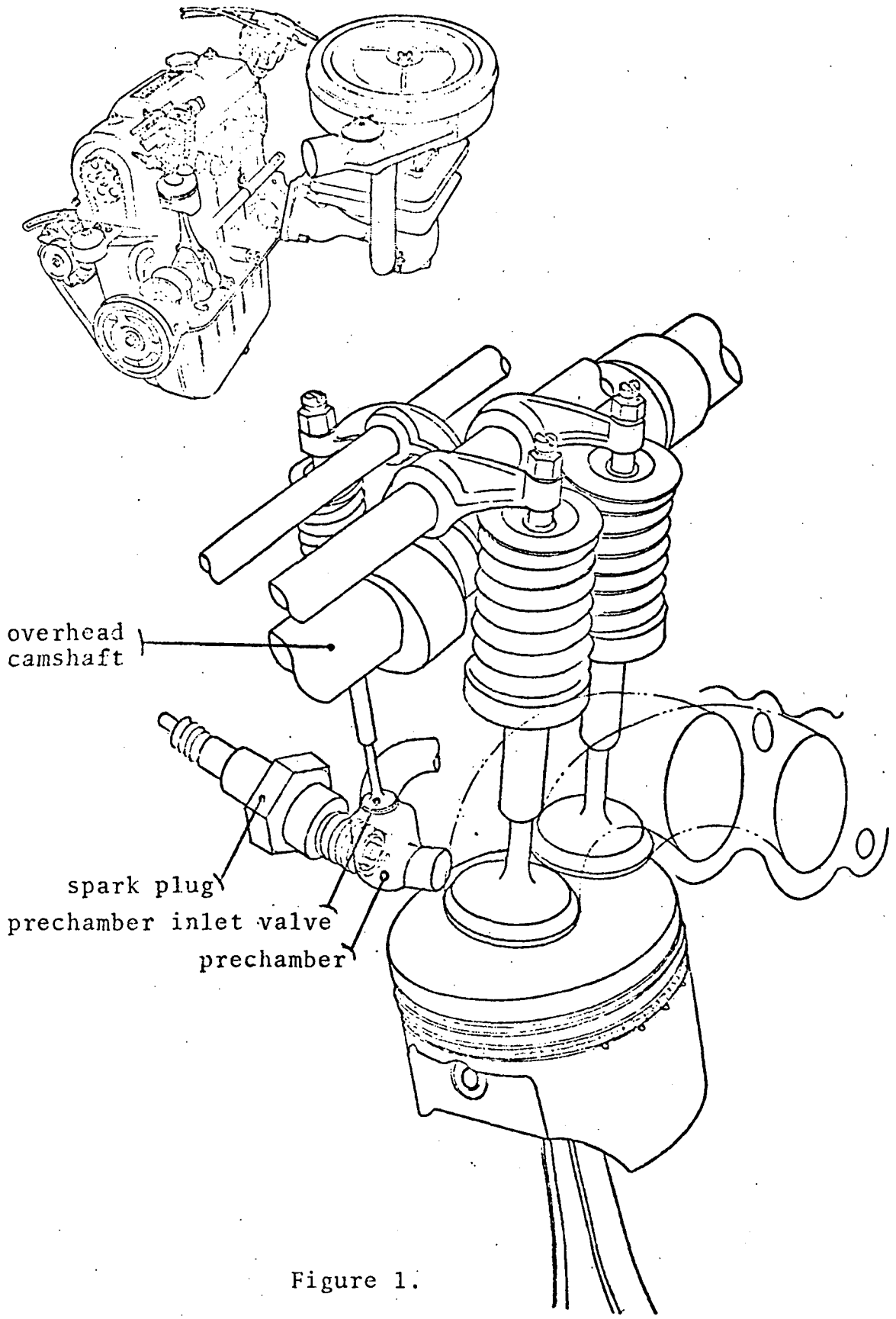

Figure 1.

Table I

Honda CVCC Powered Vehicle
1975 Federal Test Procedure
(emission data in grams per mile)

	Test Number	HC	CO	NOx	'75 FTP mpg	'72 FTP mpg
Low Mileage Car #3652	16-0109	.20	2.06	.75	22.0	20.9
	16-0114	.15	1.96	.83	22.4	21.5
	16-0117	.16	2.28	1.06	21.9	20.6
	16-0118	.21	2.24	.86	22.1	20.9
	16-0122	.19	2.05	.94	22.1	20.9
	AVERAGE	.18	2.12	.89	22.1	21.0
50,000 Mile Car #2034	16-0106	.19	1.73	.65	21.1	20.0
	16-0110	.25	1.73	.57	22.2	19.7
	16-0115	.26	1.70	.64	21.0	19.8
	16-0116	.26	1.85	.73	20.8	19.5
	AVERAGE	.24	1.75	.65	21.3	19.8
Low Mileage Back-up Car #3606	16-0123	.23	2.00	1.03	20.7	19.5
1975 Federal Standards		.41	3.40	3.1		
1976 Federal Standards		.41	3.40	.40		

Table II

Honda CVCC Powered Vehicle
3000# Test Weight

	HC	CO	CO_2	NOx
Bag 1 (calculated) grams	2.45	19.01	1654	6.08
Bag 2 (measured) grams	.14	7.17	1789	5.39
Bag 3 (measured) grams	1.59	13.58	1490	6.47

	HC	CO	NOx	'75 FTP mpg	'72 FTP mpg
Calculated Composite gpm	.28	3.08	1.56	19.4	18.7
1975 Federal Standards	.41	3.4	3.1		

LA4 fuel economy of average 3000# 1973 vehicles[1] 16.2
LA4 fuel economy of average 3000# 1967* vehicles[1] 15.4

*no emission control systems

[1] "Fuel Economy and Emission Control", EPA-OAWP-MSPC, Nov. 1972

Table III

Honda CVCC Vehicle #3652

Steady State Emission Levels
and Fuel Consumption
(emission data in grams per mile except for the idle mode where data is reported in grams per minute)

MODE	HC	CO	NOx	MPG
Idle	.06	.23	.02	*
15 mph cruise 2nd gear	.08	1.92	.44	21.0
30 mph 3rd gear	.01	.67	.50	29.2
45 mph cruise 4th gear	.007	.41	.75	32.1
60 mph cruise 4th gear	.005	.36	.645	33.0

*idle fuel consumption = 228.6 minutes/gallon or 12.5 grams per minute.

Table IV

Airborne Particulate Emissions
(all data in grams per mile)

Vehicle	Fuel	'75 FTP	Hot '72 FTP	60 mph Steady state
Honda CVCC	lead-free	.036	.040	.012
1972 Chevrolet	lead-free	---	---	.009
1971 Chevrolet	.5 gpg lead	---	---	.021
1970 Chevrolet	3.0 gpg lead	---	---	.110

Total non-airborne particulates collected in Dow dilution system 27 feet downstream of tailpipe during all Honda testing (146 miles) equalled 1.9086 grams. The average gpm of non-airborne particulates equalled .013.

ATTACHMENT I

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.

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EPA TESTS SHOW HONDA ENGINE MEETS 1975 FEDERAL EMISSION STANDARDS

The Environmental Protection Agency has released test results showing that an auto engine developed by Honda Motor Company meets the Federal emission requirements for the 1975 model year without the use of exhaust after-treatment devices such as catalytic converters.

The tests, which do not constitute official EPA certification, were conducted on three vehicles during December, 1972, in EPA's laboratories in Ann Arbor, Michigan. The results showed hydrocarbon emissions to be about one-half of the allowable 1975 level, carbon monoxide emissions were more than one-third lower, and nitrogen oxides emissions about two-thirds lower.

The vehicles supplied by Honda were equipped with the company's Compound Vortex Controlled Combustion Engine, which is similar in concept to the stratified charge engine. Each cylinder of the engine has a double combustion chamber. The smaller "prechamber" is supplied with a rich air-fuel mixture while the larger main chamber is supplied with a very lean mixture. Combustion is initiated in the prechamber. The burning gases then expand into the main chamber to ignite and burn the lean mixture.

(more)

The overall air-fuel mixture is much leaner than in a conventional engine, which requires a much richer mixture for ignition.

The vehicle model tested was the new Honda "Civic," a car not yet imported into the United States. The vehicle is about the size of the smaller American compacts. The Civic weighs about 1600 pounds and carries four passengers.

Two of the vehicles had only about 1500 miles on them at the time of the EPA tests. The third had completed a 50,000 mile durability run when tested.

The test report issued by EPA concluded that the engines achieved "lower emission levels than any other gasoline fueled engine without after-treatment devices ever tested by EPA."

Other findings in the report are:

--There does not appear to be a significant fuel economy or driveability penalty associated with the engine.

--It was estimated that the engine could probably have met the 1975 standards even if installed in a vehicle weighing 50 percent more than the vehicle tested.

--Additional NO_x control would be required to meet the 1976 standards. However, the vehicles tested did not employ devices or special methods for NO_x control.

Copies of the Honda test report are available from the Press Office, Office of Public Affairs, EPA, 401 M St., S.W., Washington, D.C. 20460.

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