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HONDA MOTOR COMPANY'S CVCC ENGINE

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JULY 1980

FINAL REPORT

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16. Abstract

Honda Motor Company of Japan in a four-year period from 1968 to 1972 designed, tested, and mass-produced a stratified charge engine, the CVCC, which in comparison to conventional engines of similar output at the time was lower in CO, HC and NO_x emissions and higher in fuel economy. Honda developed the CVCC engine without government assistance or outside help. Honda's success came at a time when steadily increasing fuel costs and the various provisions of the Clean Air Act had forced U.S. automakers to consider possible alternatives to the conventional gasoline engine. While most major engine manufacturers had investigated some form of stratified charge engine, Honda's CVCC was the only one to find successful market application.

This case study examines the circumstances surrounding the development of the CVCC engine and its introduction into the Japanese and American markets.

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PREFACE

In the future, further reductions in fatalities, fuel consumption, and emissions associated with automobile use will be needed. To insure that these goals are achieved, it is necessary to understand more thoroughly the process by which the development, implementation, and adoption of innovative automobile technology occurs. The current study, focussing on the development and diffusion of Honda's CVCC stratified charge engine, provides an important link in addressing these questions.

In the late sixties, it was widely believed that achievement of lower exhaust emissions required the adoption of alter-treatment devices such as the catalytic converter. Honda, a late entrant into the automarket, rejected this conventional wisdom and instead focussed on refining the concept of charge stratification. Thus, examination of the development of the CVCC engine highlights the role of corporate philosophy and organizational structure, and the manner in which federal regulations can spur innovation by creating new market opportunities.

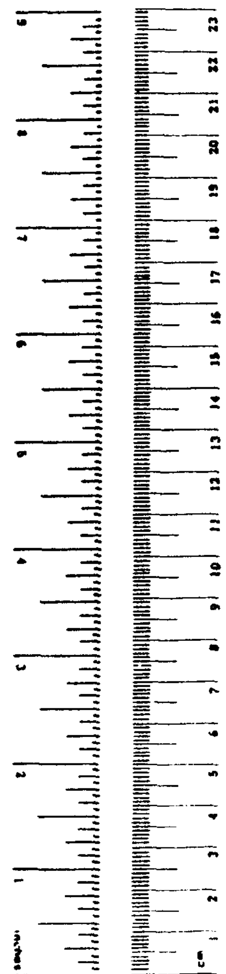
This work was carried out as part of the Implementation of Innovation in the Motor Vehicle Industry Program (HS-928), at the Transportation Systems Center, under the sponsorship of Mr. Sam Powel, III, Office of Research and Development, National Highway and Traffic Safety Administration. The contract technical monitor was Dr. Bruce Rubinger.

Although the authors take sole responsibility for the information contained in this report, they wish to acknowledge the guidance and suggestions of the contract monitor, Dr. Bruce Rubinger. Finally, the authors which to thank Professor Koichi Shimokawa, an auto industry historian, for his many helpful comments.

METRIC CONVERSION FACTORS

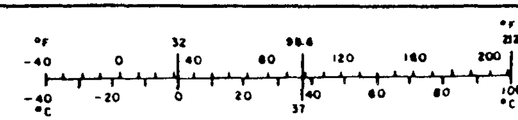
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

Honda Motor Company of Japan in a four year period from 1968 to 1972 designed, tested, and mass-produced a stratified charge engine, the CVCC, which in comparison to conventional engines of similar output at the time was lower in CO, HC, and NO_x emissions and higher in fuel economy. Honda developed the CVCC engine without government assistance or outside help. Honda's success came at a time when steadily increasing fuel costs and the various provisions of the Clean Air Act had forced U.S. automakers to consider possible alternatives to the conventional gasoline engine. While most major engine manufacturers had investigated some form of stratified charge engine, Honda's CVCC was the only one to find successful market application.

This case study examines the circumstances surrounding the development of the CVCC engine and its introduction into the Japanese and American markets. It briefly describes Honda's history as a leading manufacturer of motorcycles and general purpose engines. The case makes a number of points. Compared to other Japanese automakers, Honda entered the automaking field relatively late. It was attracted by the rapidly growing domestic and export market for passenger cars. In addition, it was encouraged by the Japanese Government's strong industry protection and support measures. Though entering late into the market, Honda was confident that its technical and marketing abilities, honed by Honda's experience with motorcycles and racing engines, would establish the company quickly and successfully.

However, by the mid-sixties, Honda held less than five per cent of the domestic market for passenger cars. It became increasingly clear to Honda's management that the company needed a significant innovation if it were to survive and to compete successfully against companies like Toyota and Nissan, which had larger financial resources and greater model differentiation. In this context, Honda saw a ready market for a low-polluting, fuel efficient engine.

In their search for an innovative engine, Honda's engineers rejected alternative power plants like the Wankel, diesel, steam, and electric as being incompatible with their research criteria of an engine that was durable, reliable, inexpensive, and mass-producible within a few years, as well as good in fuel economy and low in emissions. They decided to develop the fifty-year old idea of charge stratification and took as their point of departure the amply documented work already done on stratified charge engines. By the time Honda had decided to develop the CVCC engine, a number of experimental stratified charge engines had reached high states of development. These engines included the Russian Nilov engine, Texaco's TCCS, Ford's PROCO, and Curtiss-Wright's stratified charge rotary engine. Of these, the last three had never been produced.

Honda's ability to marshall its resources successfully in a brief period toward the design, development, and production of the CVCC engine must be seen as the result of a variety of interrelated factors. Honda's technical abilities had been developed over the previous years in its work with motorcycle and automotive commercial and racing engines. Moreover, the company had an unusual organizational structure. It supported a well-financed, autonomous research subsidiary which was virtually a seperate operating company with its own management and funding. Such a structure, divorced from the parent company's influences, encouraged experimentation among its individual engineers. Also the parent company had an industry-wide reputation for being an engineering company, dominated by an engineer, Mr. Honda, who directed a vast amount of the company's financial and technical resources into innovation. In addition, the company held to a philosophy of technical self-suffiency with strong funding of R&D and a policy of "in-house" development of all its important technology. All of these factors led to a distinctive management of the innovation process itself and played a major role in Honda's development and production of the CVCC engine.

Detroit was quick to criticize the new engine and minimize its importance for the U.S. auto industry. Its engineers argued that the CVCC had considerable drawbacks in fuel economy and power output. Also, they believed that the CVCC presented serious and costly conversion problems for U.S. industry and doubted that the new engine could be successfully converted to big V-8's. Tests by the EPA, Honda, and others disproved these contentions.

Honda introduced the new engine in its Civic model in Japan in 1973 and in the U.S. in 1975. Immediately, it met with a highly successful market acceptance and strengthened substantially Honda's market position at home and abroad. Honda's CVCC-equipped cars won numerous accolades from the media and, from 1974 through 1977, were rated by the EPA as cars with the highest estimated gas mileage of the 300 cars tested. Due to the CVCC's success Honda, by 1977, had captured 7.1 percent of the domestic market and has increased its total passenger car production over 245 percent since 1972. Moreover, Honda had built up a significant export market for over half of its total output, ranking fourth in the U.S. in unit sales of imported cars.

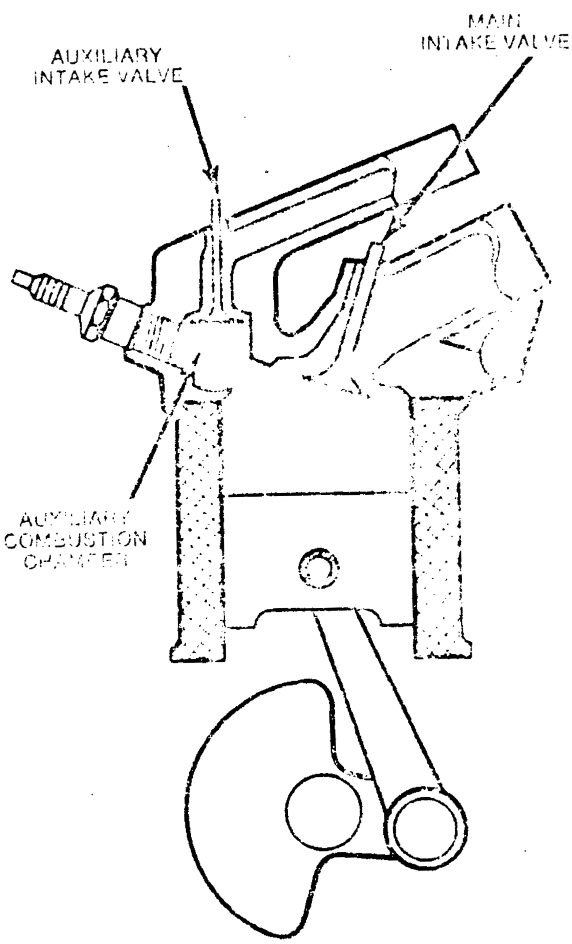
1. THE HONDA MOTOR COMPANY'S CVCC ENGINE

During the early seventies in the United States, automobile emissions accounted for about 50 percent of the pollutants entering the atmosphere, about 20 percent of total energy consumption, and 50 percent of all petroleum consumption.[1] It is clear that great pressures, social and economic, existed at the time to produce a cleaner and more fuel efficient automobile engine. Honda Motor Company, in a period of less than five years, designed, developed, and put into production an engine, the CVCC, which met the 1975 federal emission standards for unburned hydrocarbons (HC), carbon monoxide (CO), and nitric oxide (NO_x) without the use of costly add-on devices. The CVCC not only satisfied both requirements of low pollution and low fuel consumption but, unlike the majority of alternative power plants proposed during this time, was a reliable, durable, easily maintained and operated, and economically mass-producible engine.

1.1 DESCRIPTION AND OPERATION OF CVCC

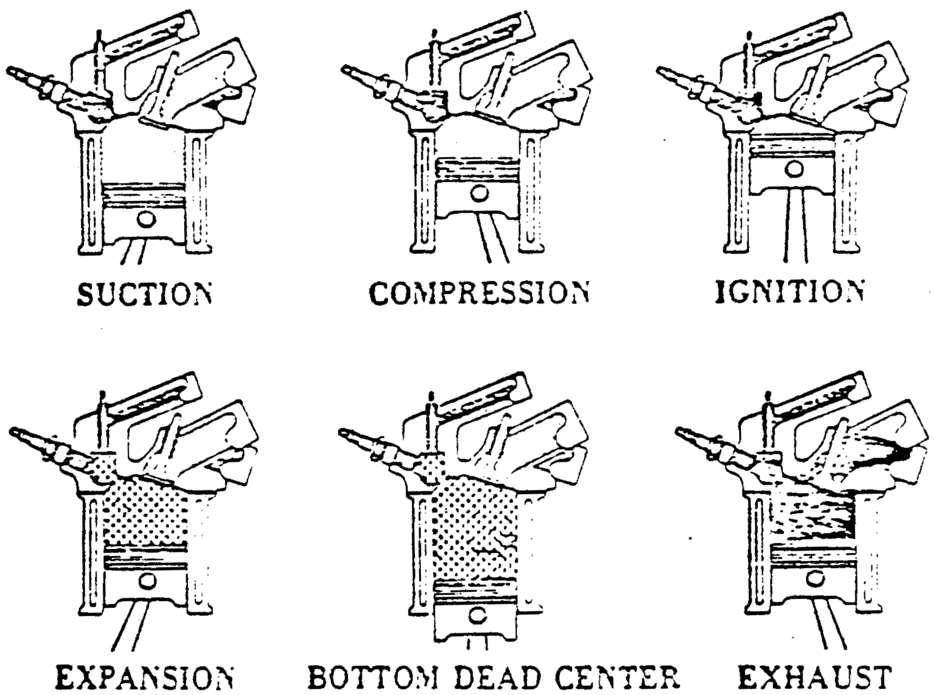
The basic structure of Honda's CVCC engine is the same as that of a conventional internal combustion engine, except for a small auxiliary combustion chamber around the spark plug and a small additional auxiliary intake valve that is fitted to each cylinder (Figure 1). The auxiliary or precombustion chamber is positioned adjacent to the main chamber. In addition, the CVCC engine is fitted with a three-barrel carburetor with conventional primary and secondary throats that feed the main intake valves and a third small venturi that feeds only the auxiliary chambers.

The CVCC's operation is similar to the cycle of a conventional internal combustion engine (Figure 2). During the piston's suction stroke, the carburetor injects a rich air-fuel mix (about 4 to 1) into the prechamber. A leaner mix (about 20 to 1) is injected into the main cylinder. The rich mix accounts for about 5 percent of the total charge and the lean mix takes up approximately 95 percent; thus, the fuel proportions are such that the overall feed



SOURCE: "Civic 1200 and Civic CVCC for 1978," Honda Motor Company publication, 1977.

FIGURE 1. DESCRIPTION OF CVCC ENGINE
Honda Motor Company



SOURCE: Honda Motor Company's letter-response to National Highway Traffic Safety Administration, May 16, 1977, p. 95.

FIGURE 2. OPERATION OF CVCC ENGINE
Honda Motor Company

to the cylinder is relatively lean. The subsequent compression stroke insures that the charge remains stratified by pushing back into the prechamber any rich mix that has seeped into the main chamber. The spark plug ignites the rich mix which burns quickly. This burning rich mix, in turn, ignites the leaner mix. Combustion in the main chamber takes place slowly throughout the expansion stroke. Finally, the piston completes the cycle by moving up, forcing the spent gases through the open exhaust valve.[2]

With its alteration in engine design, the CVCC cuts down on excess oxygen and limits peak combustion temperature sufficiently to minimize formation of NO_x. At the same time, the engine operates in an overall lean oxidizing environment and slows down the cooling process in the main cylinder, more so than is done in a conventional engine, allowing more time for complete combustion of fuel, and thus insuring adequate burning of HC and minimum formation of CO. Moreover, the engine runs on a much lower average fuel-air ratio, meaning considerable fuel economy.

1.2 Brief History of Honda Motor Company

The company responsible for the CVCC's development was founded in 1948 by Soichiro Honda, a self-trained engineer. He began by manufacturing and by rebuilding motors for bicycles. Soon after, in response to post-war Japan's need for low-cost transportation, Honda manufactured and marketed small 100 c.c. motorcycles, later introducing various other motorcycles varying in size up to 350 c.c. By 1956, Honda had become the largest manufacturer of motorcycles in Japan in terms of units of production. Its introduction in 1958 of the "Super Cub," a 50 c.c. motorcycle designed especially for commuting, shopping, and delivery purposes, further secured Honda's leading market position. Later, Honda added to its product line portable generators, outboard motors, general-purpose engines, and agricultural machinery. (See Appendix for chronology of product lines.) Since 1960, Honda has been the largest manufacturer of motorcycles in the world.[3]

1.2.1 Four-Wheeled Motor Vehicle Production

Applying engineering technology acquired in the development and manufacturing of motorcycles, Honda entered the four-wheeled motor vehicle field in 1963. It began producing 360 c.c. mini-trucks and 500 c.c. sports cars. Honda's total production of commercial vehicles was 44,000 units in 1965 and 55,000 units in 1966.[4] Of specialty sports cars, its total production was 9000 units in 1965 and 3000 units in 1966[5] (Tables 1 and 2). In both years it held approximately 2.5 percent of the domestic market share and conducted a negligible export business for four-wheeled vehicles.

TABLE 1. PRODUCTION OF PASSENGER CARS ANALYZED BY MOTOR MANUFACTURERS 1965-69 ('000s)

Honda Motor Company

Manufacturer	1965	1966	1967	1968	1969
Toyota	236	316	477	659	964
Nissan	170	232	352	572	698
Honda	9	3	87	187	233
Toyo Kogyo	81	92	129	178	201
Mitsubishi HI	46	76	106	130	128
Fuji HI	37	59	94	104	125
Suzuki	2	3	26	96	122
Daihatsu Kogyo	11	22	60	89	105
Isuzu	31	33	39	40	36
Hino	26	20	5	1	neg.
Total	649	856	1375	2056	2612

SOURCE: Motor Vehicle Statistics of Japan, 1978, p. 10-11.

TABLE 2. PRODUCTION OF COMMERCIAL VEHICLES ANALYZED BY MAJOR MANUFACTURERS 1965-69 ('000s)

Honda Motor Company

Manufacturer	1965	1966	1967	1968	1969
Toyota	241	271	355	438	507
Nissan	175	240	374	408	451
Toyo Kogyo	193	207	259	283	227
Mitsubishi HI	119	163	211	230	209
Daihatsu Kogyo	137	152	165	171	160
Honda	44	55	62	132	132
Isuzu	67	76	94	108	119
Suzuki	40	65	89	97	116
Fuji HI	54	83	79	76	63
Hino	25	28	28	33	39
Aichi Machine	34	39	43	39	22
Nissan Diesel	5	7	11	15	18
Others	neg	neg	neg	neg	neg
Total	1134	1386	1770	2030	2063

SOURCE: Motor Vehicle Statistics of Japan, 1978 p. 10-11.

In 1967, Honda began to produce and market mini-passenger cars with 360 c.c. engines. One interpretation of Honda's move into the mini-car business is that the company decided to trade-up with their market from low-cost motorcycles to low-cost four-wheel transportation. The tiny sedan, an air-cooled, two-cylinder, front engine automobile sold very well. Honda's total production of passenger cars increased dramatically to 87 thousand units in 1967, 187 thousand units in 1968, and 233 thousand units in 1969.[6] During these years, Honda's domestic market share rose rapidly from 6.9 percent in 1967 to 10.7 percent in 1969 (Table 3). By the time its production of mini-cars ended in 1974, Honda accounted for 30 percent of the total mini-car production in Japan since 1967, making it Japan's largest producer of mini-cars for that period.[7]

1.2.2 Relations With Business Associations

Throughout this period of the early sixties when the company set the foundations for its automotive business, Honda pursued a policy of aloofness from the powerful politico-economic business organs that directed Japan's economy--The Keidanren, Nikkeiren, Kezai Doyukai, and Nissho.[8] The powerful and prestigious Keidanren speaks mainly for big business and exerts considerable influence on government policy. The Nikkeiren or Federation of Employers' Associations concerns itself with the employers' interest in labor-management issues. Nissho, the oldest of the major business organizations, lobbies mainly for the interests of Japan's small and medium-size enterprises. The Kezai Doyukai is like the U.S. Committee for Economic Development and is particularly interested in developing new business ideology. All of these associations maintain close connections with Japan's various ministries, the Diet, and key government officials.[9]

Honda's distance from these organizations was one way in which the company differed significantly from Japanese companies as a whole and Japan's automakers in particular. Honda's refusal to play a role in the business organizations actually began in 1951 when it declined an offer to participate in a private meeting of major industrialists and manufacturers to work out policy incentives for Japanese exporters and to ask the government to adopt more stringent protective measures to promote export and discourage import.[10] Mr. Honda's answer at this time to the import problem facing post-war Japan is indicative not only of the company's attitude toward government-business cooperation, but of Honda's confidence in its technical abilities:

> I resolved to discourage imports and promote exports by enhancing technology and developing engines that were the highest performance in the world...if Japanese technology were good and Japanese products were high in quality, then the Japanese would not have to import foreign-made products.[11]

TABLE 3

DOMESTIC MARKET SHARES OF JAPANESE MOTOR VEHICLE MANUFACTURERS

Honda Motor Company

Company	1965 %	1966 %	1967 %	1968 %	1969 %
Toyota	24·8	23·6	24·2	24·5	26·9
Nissan	15·9	21·2	21·4	21·6	22·1
Toyo Kogyo	15·9	14·4	12·9	11·3	9·7
Mitsubishi HI	9·5	10·8	11·0	9·8	8·8
Honda	2·5	2·8	5·0	8·6	8·9
Daihatsu Kogyo	8·6	8·0	7·7	7·3	6·4
Suzuki	2·5	3·1	4·1	5·5	6·2
Fuji HI	5·5	6·5	6·1	4·9	4·8
Isuzu	4·5	4·6	4·1	3·8	3·4
Aichi Machinery	2·0	1·9	1·5	1·1	0·6
Hino	2·2	2·0	1·1	0·8	0·9
Nissan Diesel	0·2	0·4	0·4	0·4	0·4
Prince	5·0	—	—	—	—
Others	0·1	neg	neg	neg	0·5
Imports	0·8	0·7	0·5	0·4	0·4
Total	100·0	100·0	100·0	100·0	100·0

SOURCE: P. Baynes, Japan: <u>Its Motor Industry and Market</u>, (London, Motor Manufacturing, EDC, 1971), p.140.

This same reluctance to rely on Japan's extensive government-business associations and, instead, tenacious reliance on its own resources, also characterized Honda's sales and marketing philosophy at this time. Unlike most Japanese companies who used the enormous resources of the Japanese Trading Companies like Mitsubishi Shoji in the U.S., Honda chose to go its own way, researching the market and selling its products through its own marketing subsidiary in Los Angeles.[12]

1.2.3 Government Support and Protection Measures

Despite its aloofness from Japan's powerful business-government associations during the early sixties, Honda undoubtedly shared in the benefits of Japan's comprehensive structure of protection and domestic incentives. In 1952, Japan's Ministry of International Trade and Industry (MITI) had adopted a variety of measures strongly favorable to domestically produced small passenger cars, engines, and automobile parts and accessories. These measures had included import restrictions, protective tariffs, government subsidies, excise taxes, foreign exchange controls, and a special depreciation system. MITI, in 1955, had defined the objectives of these measures:

> ...by means of positively fostering the small car passenger car industry as a new industry, to expedite the expansion of related industries, expansion of employment, and enhancement of the technical level, thus preparing the ground for the small passenger car industry to develop as an export industry and raising the national living standard through the popularization of passenger cars at home.[13]

Honda entered the automobile market in 1963 at a time when the industry was still highly protected and very profitable. Certain protection measures clearly helped an infant automaker like Honda, providing it with the opportunity to build an auto business from the ground up without threat of crippling competition from abroad. The government kept out foreign producers' onshore investment through strict legislation by requiring its authorization of all foreign capital investment. Through quotas, tariffs, and the commodity tax structure, the government encouraged domestic industry growth, while protecting the industry from imported goods. Stringent quantitative restrictions were set, for example, on importation of auto engines. Japan, moreover, encouraged its industry's small passenger car production by exceptionally high tariff rates on imported small cars and by a commodity tax rate structure biased in favor of small cars and against the larger U.S. models (Tables 4 and 5).

Of the various support measures adopted by the government, Honda directly benefited from special accelerated

TABLE 4

AUTOMOBILE IMPORT TARIFF RATES (MAY 31, 1970)

Honda Motor Company

		Fixed rate	GATT rates
Automobile	passenger car	40%	35% (with wheelbase above 254 cm) 30% (with wheelbase below 254 cm)
	truck	30%	27% (with wheelbase [illegible] 254 cm and [illegible] capacity above [illegible])
Automobile parts		30%	30%

SOURCE: H. Uneo and H. Muto, The Automobile Industry of Japan Japanese Economic Studies, Fall 1974, p. 14

TABLE 5

EXCISE TAX RATES ON AUTOMOBILES (APRIL 21, 1959)

HONDA MOTOR COMPANY

High-class passenger cars	50%	(with wheelbase above 305 cm or cylinder capacity above 4,000 cc)
Medium-sized passenger cars	30%	(with wheelbase above 245 cm and below 305 cm or cylinder capacity above 1,500 cc and below 4,000 cc)
Small passenger cars	15%	(with wheelbase below 245 cm and cylinder capacity below 1,500 cc)

SOURCE: H. Uneo and H. Muto, The Automobile Industry of Japan Japanese Economic Studies, Fall 1974, p. 14.

depreciation allowances and exemptions of import duties on necessary imported automaking machinery and equipment. The government authorized a depreciation by one-half in the first year after acquisition for certain machinery and, for other selected essential machinery, an annual 50 percent extra addition to the approved depreciation rates during a three-year period. Of less importance to Honda were the government's support policies encouraging the importation of foreign technology, the special government subsidies, and the low-interest financing arrangements.

Japan's sustained industry protection and encouragement allowed Honda to establish itself in the market relatively late (against much larger domestic producers) and to develop its production capabilities. Moreover, it is important to see that Honda entered the automobile manufacturing field at a time of rapid progress in Japan's overall domestic motorization. Because of the rise in individual income level, the improvements to Japan's highway system, and the decline of automobile prices, Japan's stock of three- and four-wheeled vehicles increases rapidly from 5 to 15.4 million units between 1964 and 1969.[14] By the time that Honda began production of passenger cars, domestic demand had shifted dramatically. Trucks, buses, and commercial vehicles which as recently as 1962 had accounted for as much as 70 percent of total automotive production, by 1968 were only 50 percent. By 1971, the percentage would decline to 36 percent.[15]

Most government supports remained in effect throughout the sixties, though, in certain cases, tariffs, duties, and quotas were liberalized from 1965 to 1971 after Japan's entrance in the OECD. Following the Kennedy Round negotiations in 1967, Japan eased import restrictions on large passenger cars from 35 to 17.5 percent and small passenger cars from 40 to 34 percent. Japan, at the 1968 Japan-U.S. automobile negotiations, eventually settled on a policy of complete liberalization of import quotas by 1972, the acceptance on home soil of joint-venture, knock-down assembly companies, and further reductions of the tariff rates on passenger car imports.

1.3 RESEARCH AND DEVELOPMENT

1.3.1 Floating Research

The year following its entry into the market for four-wheeled vehicles, Honda began to design and build "formula" racing cars for international Grand Prix racing. From 1964 to 1968, competitive racing not only advertised internationally the Honda name, but helped to develop Honda's automotive engine technology. Indeed, Honda's interest in Grand Prix racing during this period was a deliberate investment in "floating research." Explained Mr. Honda:

> We want to apply the knowledge we gain in the race to production. By improving the technical qualities of our engines for racing, we are able to improve our standard cars.[16]

Honda invested approximately $2 million between 1964 and 1966 in this form of research. In 1969, Honda began production of a sub-compact passenger car that reflected some of the engine technology developed in the company's earlier work with racing cars.[17] Moreover, the development of the CVCC engine leads back directly to Honda's racing car investments. The majority of Honda's engineers who later worked on the CVCC development and design had had experience in Honda's earlier work with both racing motorcycles and automobiles.[18]

1.3.2 <u>Organization and Philosophy</u>

It was during this same time, the early sixties, that Honda reorganized its research and development center. It dissolved the company's previous research arm, Technology Research Institute, and established a new, separate, and wholly owned subsidiary, Honda Research and Development, Ltd. It is important to note that Honda organized Honda R&D Ltd. in such a way as to allow it to conduct its activities independently from the parent company. The decision as to what kind of research to undertake, as well as the financing of it, rested entirely with Honda R&D Ltd. The research subsidiary, moreover, was responsible for its own management and organization. In exchange for all technology developed and designed by Honda R&D Ltd., the parent company provided Honda R&D, Ltd. with monthly funding equivalent to 2.5 percent of Honda Motor Company's unconsolidated net sales for the prior month.[19]

Autonomous and well financed, Honda R&D Ltd. reflected the company's belief that the organizational structure of a research institute differs fundamentally from that of a manufacturing concern.[20] In the early sixties, Mr. Honda, who was responsible for establishing the independent research center, felt that the parent company's concerns for maximum efficiency and profits necessarily compromised a spirit of innovation whose life-blood was risk and multiple failures. He explained his decision to create an independent research company in this way:

> Had we left research in the middle of Honda Giken Kogyo (the parent company), it would have been treated as a step-child, for that company's purpose is the pursuit of profits. Since good research cannot be treated as simply as an appendage of manufacturing, I decided that it would have to be a separate, distinct operation in our family companies.[21]

The chief engineer at Honda's 1600 man R&D operation, Tadashi Kume, concurred with Mr. Honda's sentiments, adding that, with R&D set up as a separate company, the engineers have a feeling of greater independence and, consequently, function in an environment where "failure is a daily occurrence."[22]

Such an environment, Kume argued, is necessary for a productive, creative research group.

Internally, Honda R&D Ltd. was structured so as to best encourage engineering innovation. In part, this had to do with the research center's encouragement of the individual engineer. Kawashima, Honda's current president and past director of research operations, explained that Honda's

> ...R&D system is such that each individual is given an opportunity to do whatever he would like to do. He is free to make any proposal and take responsibility for any research he wants to do.[23]

A sense of daring also characterized Honda R&D Ltd. A leading authority on Japan's auto industry, Kyoichi Yamaguchi, commented that "the big automakers may have something good in their laboratories, but they often start thinking about marketing costs or retooling."[24] Honda, he pointed out, liked risks and tended to pursue aggressively its development work, guided less by marketing and styling considerations and more by performance and social needs. For example, unlike most automakers which use a basic engine for all models to save money, Honda preferred to experiment continually with many engine types. Consequently, the company was exceptionally quick in designing, developing, and producing new engines.[25]

1.3.3 Technical Self-Sufficiency

The unique nature of Honda's research subsidiary accounts, is responsible, in part, for Honda's difference from other Japanese automobile manufacturers with regard to the source of its technology. Unlike other Japanese automakers, Honda, during the early sixties, established no technical links to foreign companies. Japan's auto industry, particularly in the late fifties and early sixties, made every effort to gain the latest in technology and research from abroad. By doing so, Japan's automakers hoped to build up quickly to international competitive standards. The Japanese purchased innumerable licensing agreements from U.S. and European firms. All told, these agreements cost the Japanese $488 million in royalty payments to foreign firms in 1971, 53 percent of which went to U.S. firms.[26] That Japan's post-war automobile development relied heavily on U.S. invention and less on indigenously developed technology, is reflected in the disparity in the number of patents held by automotive firms in each country. As of 1967, Toyota and Nissan together held 400 patents compared to GM's 9811, Ford's 1583, and Chrysler's 861.[27]

By contrast, Honda's automobile technology is rooted in its own research and development efforts and resources. The company espouses a philosophy of technological self-sufficiency and "in-house" development. Masaru Ibuka, Sony's Chairman of the Board, saw Honda's reliance on its own technological innovation as characteristic of the company's founder:

Honda's unique feature is that once he has established a goal he wants to achieve he will get technology or establish new technology for all the requirements that are necessary to achieve that goal. Sometimes it may be a specific technical objective and other times it may be a little more general, such as an engine that does not pollute.[28]

Clearly, Honda's strong emphasis on research and innovation is one of the principal differences between it and other Japanese companies. In general, Honda has been more eager to develop new technology. An indicator of this eagerness is Honda's heavier funding of R&D. For Japanese industry as a whole, R&D costs in 1965 remained relatively low.[29] The industry average for automobile manufacturers, in terms of the ratio of R&D expenditure to total sales, was 1.59 percent compared to the U.S. average of 2.55 percent.[30] Japan's Big Two, Nissan and Toyota, averaged 1.94 percent, a substantially lower average than the U.S. Big Three's approximately 3.00 percent.[31] Honda, for this same period, kept pace with the U.S. automakers' average of 2.5 percent. The CVCC engine is but one example of the results of Honda's commitment to research and development. Another example of the company's technical superiority is its development in 1968 of an automatic transmission for small cars. In contrast to the other Japanese firms, Honda designed and developed a transmission without American and in particular, Borg-Warner's technology.

1.3.4 Traditional Employment System

Honda's research subsidiary, by virtue of its organization and philosophy, distinguished the company from most other Japanese firms, yet in some ways Honda's organization and operations were traditionally Japanese. Its employment system, the shusin-koyo or one-company, lifetime employment, with emphasis on compensation in terms of company benefits and on logaylty to the company was throughly Japanese. Unlike the fluid job mobility of the U.S., Honda's employees stayed with Honda all their working career. It was a form of tenure with attendant benefits of job security and integration with the company. Like most Japanese companies, Honda offered substantial non-salaried inducements like home financing, hospital insurance, family-recreation organizations and monetary gifts from the company on occasions of marriage, birth, and death. Moreover, the relationship between employee and employer was not sufficiently explained in contractual terms as it might be in the U.S. The relationship was more paternal and familial, more like an extended family. Consequently, worker identity and pride were integral to the company's operations. Honda's only exception to this traditional employment arrangement was in the area of seniority. Usually, an employee's length of service to the company was a substantial test of his authority and capability in promotion and compensation. Seniority could be as heavily rewarded as intelligence. Honda, while not completely disregarding this tradition, emphasized the experience and responsibility of its younger employees. Indeed, its current president Kiyoshi Kawashima, at 50, is relatively young in comparison with other Japanese corporate leaders.

1.4 RESEARCH AND DEVELOPMENT OF THE CVCC ENGINE

1.4.1 Social Context

In the mid-sixties, Honda determined to mass-produce, within a reasonable time, a reliable and durable automobile engine giving relatively clean exhaust emissions and no penalties in fuel economy.[32] Honda was aware, as were all automotive manufacturers, of the growing social and legislative pressures during the sixties, both in the United States and Japan, for curbing automobile emissions. Automobiles were a main source of environmental pollution. A 1966 survey in the U.S. estimated that, out of a total of 142 million tons of pollutants, 86 million tons, or about 60 percent, were attributable to automobiles.[33] In certain U.S. localities like Los Angeles, automotive emissions were responsible for up to 90 percent of urban atmospheric contamination.[34] Japan's pollution problem was no better. In fact, Tokyo's air pollution surpassed New York's and, world-wide, was second in severity only to Los Angeles.[35] An environmental survey of Tokyo in 1972 indicated that automobiles contributed most to each of these air pollutants--CO, HC, and NO_x. Automobiles accounted for as much as 90 percent of total CO discharges, more than 50 percent of HC discharge, and more than 33.5 percent of NO_x discharge.[36]

Pollution problems reached crisis proportions in the mid-sixties, forcing national and state legislatures to adopt a series of measures aimed at curbing exhaust emissions and stimulating auto industry efforts to find improved ways of controlling motor vehicle exhaust pollution. (See following chronology of legislation.) In the U.S., these laws applied equally to imported foreign models. California, during this decade, was the first state to legislate standards and generally set the trend for national regulation. Earlier it had prescribed standards limiting the emission of unburned HC, CO, NO_x.[37] Furthermore, it required that every new car sold in 1964 must be equipped with a device insuring more complete combustion of gasoline.[38]

California's early regulatory actions could not escape Honda's notice. Outside Japan, the U.S. was Honda's largest market for both motorcycles and automobiles and, in the U.S., California was by far Honda's best export area with Honda's highest concentration of dealers and service companies.[39] In addition, California served as Honda's home base for its overseas operations.[40]

1.4.2 Rejection of the Catalytic Converter

In its search for a low-polluting technology, Honda had experimented with after-treatment devices like the catalytic converter and, in fact, had patented an afterburner apparatus for engine exhaust gas.[41] The add-on device was also Detroit's immediate answer at the time to pollution control. When exhaust standards became mandatory nationally for 1968 model year cars, most U.S. manufacturers installed the Chrysler Clean Air Package. Two main features of the Package were the leaning-out of fuel, that is, the use of a lower gas-to-air ratio, and the retardation of the spark. Leaning-out the fuel reduced the proportion of gas burned in the combustion chamber,

SUMMARY OF SIGNIFICANT POLLUTION LEGISLATION IN U.S. AND JAPAN (1955-1972)

1955 -- Congress enacts legislation authorizing the Federal Government to conduct research and provide technical assistance to the states for control of air pollution.

1961 -- HEW's secretary asks the U.S. automobile industry to install pollution reducing devices as standard equipment on all 1964 model cars.

California requires crankcase emission devices to be installed on all cars sold in its jurisdiction. Also, the state enacted a statute requiring automobiles sold there to be equipped with exhaust controls two years after the state certifies two workable control devices.

1963 -- Clean Air Act; established a program to provide grants to the states to assist them in creating or maintaining air pollution control agencies. The Act also provided a mechanism for direct federal action on interstate air pollution problems.

California passes legislation requiring that 1964 models be equipped with a device insuring more complete combustion of gasoline. Moreover, the state adopts limits for hydrocarbon and carbon monoxide emissions.

1965 -- HEW required to prescribe standards limiting the emission of noxious fumes from automobiles.

1966 -- California adopts limit for nitric oxide emission.

1967 -- Air Quality Act; funds secured for research on pollution caused by fuel combustion, including automobile emissions.

1969 -- Air Quality Act Amendments; continued funding for research on air pollution control.

Environmental Protection Agency formed.

1970 -- Clean Air Act Amendments of 1970; provides that model year 1975 cars must emit 90 per cent less carbon monoxide and hydrocarbons than model year 1970 cars. Furthermore, nitrogen oxides in 1976 model year cars must be reduced 90 per cent compared with model year 1971.

1972 -- Japanese Ministry of Transportation establishes ordinances relating to automotive emission standards for new model as of April 1, 1975.

thus reducing the amount of unburned fuel emitted. The retardation of the spark causes the engine to run at higher temperature, thereby burning up much of the remaining gases.[42]

Despite the installation of the Clean Air Package in the late sixties, most privately owned automobiles failed to meet the federal emission standards for HC and CO. Dr. John T. Middleton, Commissioner for the National Air Pollution Control Administration, an agency within HEW charged with the authority for air pollution legislation, conceded that his agency's surveillance found a 75 to 80 percent failure rate in cars operating with the Package.[43] Moreover, there was evidence that cars equipped with the Package were consuming upwards of 10 percent more fuel, and were adding dangerous levels to the atmosphere of NO_x and lead.[44]

Before undertaking its research in to the possibilities of a stratified charged engine in 1968, Honda concluded that the use of add-on devices to reduce pollution emissions was the wrong approach. About after-treatment catalysts, Mr. Honda commented that "There is no guarantee that the catalyst will continue to work in any individual automobile, particularly in view of the problems of heat, catalyst poisoning and possible failure to repair the system in time."[45] Moreover, Honda contended, add-on devices were costly, involved heavy penalties in fuel economy, and could not control NO_x.

1.4.3 Commercial Advantages to Innovative Technology

Honda's management was aware that it was to its advantage to invest heavily in the development of an innovative, low-pollution engine. As a latecomer into the automobile field, Honda needed innovative technology to increase its market share. In the early sixties, when Honda had commenced production of small trucks and sports cars, the Japanese auto market was beginning to show considerable potential. Ownership had increased rapidly with the increase in the standard of living and improvement of the country's infrastructure. In 1962, Japan had licensed 889,032 passenger vehicles; by 1968, the figure climbed to 5,209,319 and showed no slowdown in possibilities for growth.[46] Two companies, Toyota and Nissan, dominated the industry, each with better than 20 percent of the market[47] (Tables 3 and 6).

Honda's share of four-wheeled vehicle production in Japan during this time had increased from 2.5 percent in 1965 to 8.6 percent in 1968.[48] Honda's larger market share was due in part, to the success of its 360 c.c. mini-passenger cars introduced in 1967. But, even with the introduction in 1969 of a sub-compact passenger car, it was clear that without a radical innovation by the early seventies that Honda lacked resources to challenge the bigger automakers' market share at home or abroad. Honda could not compete successfully with the large model ranges of Japan's Big Two. In 1970, Toyota offered eight main models and Nissan offered five. Honda at this time offered only three (Table 7).

TABLE 6

JAPAN'S FOUR WHEELED PASSENGER VEHICLE REGISTRATION
1951-1972

HONDA MOTOR COMPANY

year	*cars*
1951	57.533
1952	88,354
1953	114.696
1954	138.518
1955	153,325
1956	181,074
1957	218,524
1958	259.631
1959	318,758
1960	457,333
1961	663,951
1962	889,032
1963	1,233,651
1964	1,672,359
1965	2,181,275
1966	2,833,246
1967	3,836,409
1968	5,209,319
1969	6,933,732
1970	8,778,972
1971	10,572,122
1972	12,531,149

SOURCE: W. C. Duncan, U.S. - Japan Automobile Diplomacy (Cambridge, Ballinger Books, 1973), p. 150.

TABLE 7

NEW CAR REGISTRATIONS IN JAPAN, 1969, ANALYZED BY SIZE RANGE, MODEL AND MANUFACTURER ('000)

Honda Motor Company

Manufacturer	360 cc and under			361-1,200 cc			1,201-1,500 cc			1,501-2,000 cc			2,001 cc and over			Total	
	Model	No	% of total	Model	No	% of total	Model	No	% of total	Model	No	% of total	Model	No	% of total	No	% of total
Toyota				Corolla 1100	119	15·3	Corona 1500	52	19·1	Crown	67	11·8	Century	1	14·0		
				Corolla 1200	173	22·3				Crown Hard Top	21	3·7					
				Corolla Sprinter	58	7·5				2000 GT	neg	—					
				Publica 1200	59	7·7				Corona Mark II 1900	13	2·4					
				Publica Sports	neg	—				Corona Mark II 1600	103	18·2					
				Miniace	neg	—				Corona Mark II Hard Top	71	12·5					
Total Toyota		—	—		409	52·9		52	19·1		276	48·6		1	14·0	739	33·8
Nissan				Sunny 1000	106	13·7	Skyline 1500	42	15·5	Cedric	42	7·3	President	1	7·5		
				Sunny Coupe	50	6·4	Bluebird 1300	54	19·9	Gloria	15	2·6					
				Sunny Cab	1	0·1	Bluebird Coupe	30	11·0	Laurel	35	6·2					
				Cabster Coach	1	0·1				Fairlady	1	0·2					
										Skyline 2000 GT	15	2·6					
										Skyline 1800	25	4·3					
										Bluebird 1600	103	18·0					
Total Nissan		—	—		158	20·3		126	46·4		235	41·2		1	7·5	519	23·7
Honda	Honda N360	200	35·2	Honda N600	neg	0·1	Honda 1300	27	9·9		—	—		—	—	227	10·4
Toyo Kogyo	Carol 360	10	1·8	Familia 1100	44	5·6	Luce 1500	6	2·2	Luce 1800	9	1·6					
				Familia 1200	34	4·3				Luce Rotary Coupe	14	2·5					
				Familia Coupe	25	3·2				Cosmo Sports	neg	—					
				Familia Rotary Coupe	14	1·9											
				Familia SS	16	2·1											
				Bongo Coach	4	0·4											
Total Toyo Kogyo		10	1·8		137	17·5		6	2·2		23	4·1		—	—	175	8·0

SOURCE: P. Baynes, Japan: Its Motor Industry and Market (London, Motor Manufacturing EDC, 1971), p.141.

1.4.4 Rejection of Alternative Power Plants

In its search for a commercially successful, low-polluting technology, Honda's research group rejected, after a period of study, alternative power plants like the Wankel, the gas turbine, diesel, steam, and electric engines (Figure 3). While each offered specific promising features, they failed to meet Honda's research objectives of an engine that not only showed potential for low pollution and good fuel economy, but was 1) basically sound and reliable; 2) economically massed producible in the near future; 3) easily maintained and operated; 4) and an acceptable technology to the giant automakers around the world.[49] Honda wanted a design that would be licensable. The Wankel, for example, used too much fuel, and the diesel was expensive and bulky for its power output.[50] Most alternative engines, furthermore, were not compatible with existing tooling and manufacturing processes. Mass production of any of these could not be undertaken for at least ten years because of the lead time necessary for testing, development, redesign, tooling, pilot production, field experience evaluation and setting up mass-production lines.[51]

Honda, after its review of alternative power plants, decided to rely on proven technology--the internal combustion engine--and to concentrate its research energies on the problems that inhere in the combustion process itself. Honda believed that, despite its drawbacks, there were advantages to be gained from working with the conventional internal combustion, spark ignition engine. The conventional engine had proven itself reliable, durable, drivable, and responsive. It was also mass-producible. Unlike a massive switch to an alternative engine like the diesel or Wankel, changing to an altered internal combustion engine would not mean retooling plants and setting up new production technologies costing billions of dollars and upsetting a network of parts suppliers and service stations that depend for their survival on the conventional engine. However, a major problem with the conventional engine--the control of pollutants with acceptable performance and fuel economy--confronted automotive engineers in the mid-sixties as an intractable dilemma. The control of HC, CO, and NO_x emissions is problematical in the conventional internal combustion engine because the ideal conditions for low HC and CO emissions are worst for NO_x control. HC forms near the cylinder walls where the fuel mixture is too cool to burn completely. The unburned gasoline vapor that remains after combustion forms layers of HC on the cylinder head and walls and is blown out during the exhaust stroke. Another product of this partially burned fuel is CO. It forms during both expansion and exhaust strokes with especially rich fuel-air mixes. NO_x, on the other hand, forms when oxygen and

Alternate Power Source	Description	Advantages (claimed)	Disadvantages
Wankel	Rotary-piston internal combustion engine providing one power stroke for each revolution of a triangular rotor.	Small, light, quiet; few moving parts.	Poor gas mileage; expensive; requires exotic machining of trochoid chamber, short life; seal problem; NOx problem, poor oil economy—800 miles/quart.
Sanron Wankel	Rotary internal combustion engine using two rotors on a co-axial shaft to produce four power strokes per shaft revolution.	Requires no special machining of housing or rotor; long life; can be stratified for low emissions; can be converted to diesel or steam.	Concept yet to be proved.
Karol Wankel	Rotary internal combustion engine using conventional piston encased in a rotor that rotates in a fixed chamber.	Clean exhaust; few seal problems; inexpensive; small; can be converted to diesel.	Requires sophisticated machining of components; yet to be proved.
Single-rotor Wankel	Rotary internal combustion engine using one large rotor instead of two.	Less expensive than conventional Wankel engine (40 pct), small; easy to build; can be stratified.	Concept yet to be proved.
Turbine Wankel	Essentially a turbocharged rotary engine.	Half size of comparable turbocharged piston diesel engine.	All the problems of conventional turbine and Wankel; yet to be proved.
Gas turbine (Brayton cycle)	Engine consisting of compressor, combustion chamber and turbine which provides continuous internal combustion to drive car.	High efficiency; reliable; low maintenance; easy starting; vibration free; multi-fuel capability; low oil consumption; few moving parts; low emissions; fits standard vehicle	Expensive; requires large, efficient air cleaner; can't use leaded or contaminated fuel; requires precision machining of components.
Rankine cycle steam or vapor engine	Continuous external combustion engine in which high-pressure steam or an alternate working-fluid vapor is expanded in a turbine or piston-type engine to produce work.	Cleanest of all alternate engines; multi-fuel capability, can be fabricated using existing technology	Steam version requires stainless steel for combustor and generator, poor performance; freezing problem with water; control complexity; some lubrication problems
Stirling engine	Reciprocating external combustion engine with continuous combustion burner which expands gas to move a piston.	Multi-fuel capability; low emission; provides torque and horsepower equivalent to conventional internal combustion engine; uses conventional axle and transmissions.	Problem keeping helium or hydrogen working-fluid sealed in high-pressure chamber; requires stainless steel and super alloys for heater heads; cooling problems; heater heads can't be mass produced today.
Sarich's orbital engine	Non-rotating, four-stroke engine with single drum-like piston that orbits in a circular chamber.	Made largely of cast iron and aluminum; inexpensive; simple construction; 1/3 weight of Wankel; few moving parts; multi-fuel capability.	Not powerful enough for large vehicles; concept yet to be proved.
Liquid propane gas engine	Specially-designed LPG engine, or diesel engine fitted with special carburetor and fuel tank.	Reduced emissions; less engine wear; smooth acceleration; inexpensive fuel.	Questionable fuel availability; fuel storage and vehicle fueling problems.
Diesel engine	Internal combustion engine where heat of compression is used to ignite a variable mixture of fuel oil and air.	May meet future emission standards; good fuel economy; low maintenance; can be mass produced; NOx problem	Expensive; poor cold weather starting; large, heavy; noise, smoke and vibration problems.
Advanced diesel	Two-stroke, higher speed engine requiring more sophisticated combustion system.	Expected to solve most problems associated with conventional diesel.	Could not be mass produced before late 1980s; drivability may prove inadequate; larger engine needed.
Battery power fuel cell Combination heat engine and battery power	Storing power for propulsion in battery or fuel cell, or using small engine to charge battery intermittently.	Quiet; relatively low emissions.	Emissions not necessarily lower than other engines; poor acceleration, heavy, large; expensive; possible safety problems; inefficient.
Advance battery	Lithium-sulfur or sodium-sulfur battery.	Greater power; can handle larger vehicles.	Same disadvantages as conventional battery-powered vehicles; can't be mass produced until mid-1990s.

Hybrid versions of most of these engines (turbine-Wankel, turbine-diesel) are being discussed. Most hold little promise, however, because they are more complex, and combine all the problems of individual engines in one unit.

SOURCE: Iron Age, January 14, 1974, p. 45.

FIGURE 3. ALTERNATIVE POWER PLANTS, AS OF 1973
Honda Motor Company

nitrogen combine at high temperatures early in the expansion stroke. The quantity of NO_x is a direct function of high temperature and available oxygen. Low NO_x emissions require: 1) low combustion temperature and long combustion duration and 2) a fuel mixture, either very lean, or rich, that completely burns. Thus, the requirements for the successful fuel control of HC and CO simultaneously with the control of NO_x are seemingly in conflict, demanding an engine that limits the combustion temperature to a sufficiently low level while, at the same time, it maintains a high combustion temperature.

1.4.5 Stratified Charge--Its History and Development

In order to resolve this problem, Honda's engineers turned to a principle that had been known for years--the idea of charge stratification. Briefly, charge stratification provides lower flame temperatures, improved cycle efficiency, reduced heat loss, and lower pumping losses. The concept dates back to the turn of the century when examples of engines employing stratified charge were proposed.[52] Later, in the twenties, British engineer, Sir Harry Ricardo, did extensive theoretical and development work on stratified charge engines.[53] Back then, he noted that the conventional reciprocating engine held substantial potential for increase fuel capability and efficiency by shaping each combustion chamber so that it would induce a rich gas-air charge that could be ignited easily near the spark plug, while the remainder of the chamber was filled with a leaner mixture. Also, Ricardo saw in the stratified charge engine a possible answer to two design problems that perplexed his era: slow, incomplete combustion and engine knock.[54] Indeed, Ricardo's experiments went so well that, in 1922, he confidently asserted that

> There is little doubt that, sooner or later, the system of working with a stratified charge will become commercial, for, as (I have) shown, it is possible and the high efficiency theoretically obtainable from it can be approached.[55]

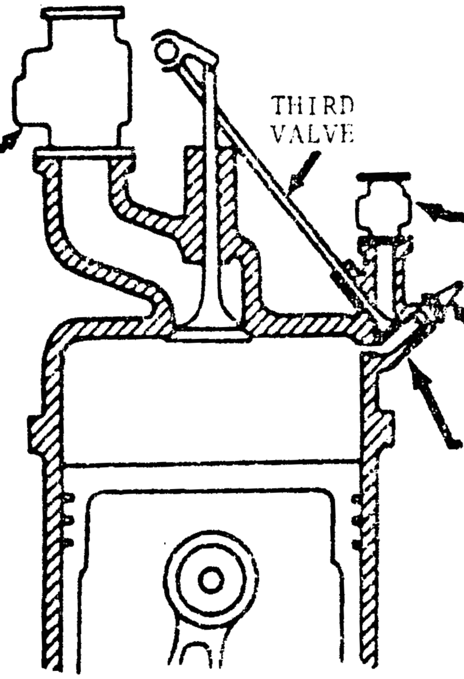
After Ricardo's charts, experimental work on charge stratification continued with the diesel, but no work was done in spark ignition engines until the mid-forties. By the mid-seventies, every automotive engine developer had at least one stratified charge engine under test."[56]

The idea of the CVCC engine started as a group idea with the setting up of a special task force in 1969 to pursue it.[57] The actual research on the CVCC, and eventual breakthrough in 1971 was essentially the work of two engineers.[58] These engineers were aware of the extensive development work that had been done on the stratified charge engine in the late fifties and throughout the sixties.[59] Without referring to any specific experimental designs, Honda's engineers mention their investigations at this time into the Russians' research.[60] In the late fifties the Russians designed and built the Nilov engine, a spark ignition stratified charged system remarkably similar in principle to Honda's CVCC engine. It was the first engine to combine a precombustion chamber with a carburetor type, gasoline-fuel power system (Figure 4). Like the CVCC, the Nilov engine employed a third valve to admit a rich mixture to the precombustion chamber.[61] Having originally developed the engine as an alternative to large fuel-inefficient marine diesels, the Russians later built a scaled-down version for use in the production model Volga car.[62] Given the CVCC engine's conceptual similarities to the Russians' Nilov engine and the fact that Honda's research team looked closely at theoretical work carried on in the mid-sixties by the Russians into charge stratification, it is conceivable that Honda's CVCC engine owes part of its development to this Russian technology.

1.4.6 Texaco's TCCS, Ford's PROCO, Curtiss-Wright's S-C Rotary and Other Stratified Charge Engines

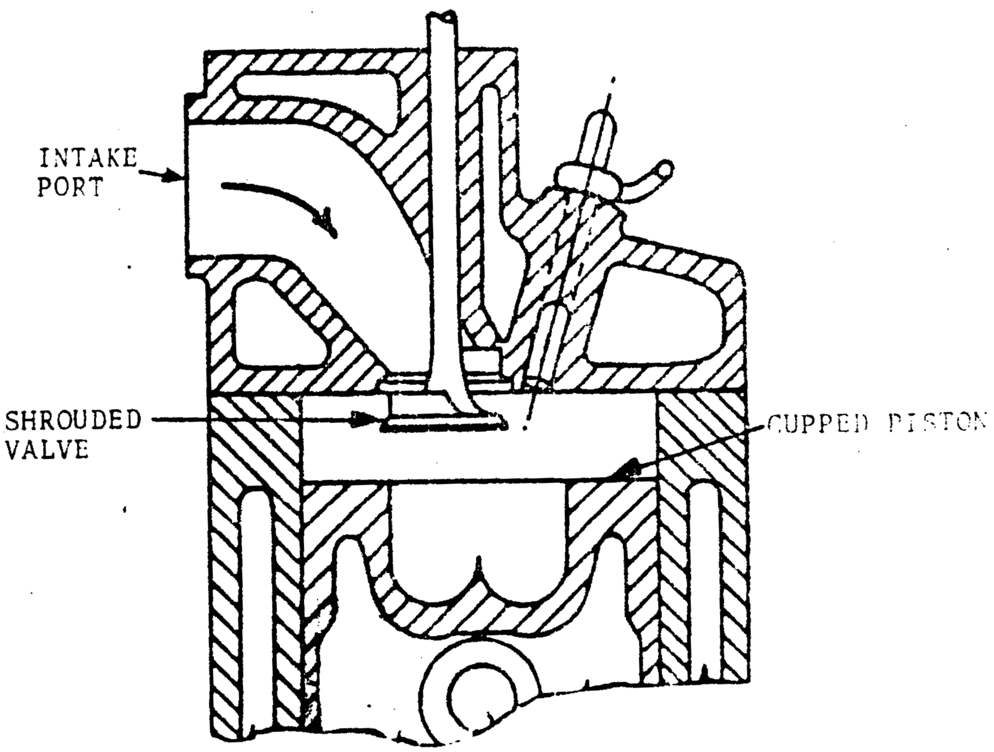
Moreover, Honda's research team looked into the growing literature in the fifties and sixties on Western developments of the stratified charge engine.[63] Honda's engineers, in a research report to the Society of Automotive Engineers, failed to single out any individual experimental engine to which they paid particularly close attention.[64] But it can be assumed that they were at least referring to those early engine developments accessible through trade and technical journals. These developments included Texaco's TCCS, Ford's PROCO, and Curtiss-Wright's rotary-stratified charge engine. All of these engines were important because, by the mid-sixties, they had reached high states of development, before Honda's design and development of the CVCC.[65] Also, they had generated ample technical material documenting their progress.

In the late forties, Texaco, under the research direction of E.M. Barber, reported on the Texaco Combustion Process (TCP), which involved a stratified charge engine with a simple, non-divided combustion chamber.[66] In 1963, Texaco, under a military contract with the U.S. Army Tank and Automotive Command documented its task of converting the military's L-141 engine into a single-cylinder, stratified charge engine. The military was interested in this engine because of its multifuel capability and improved fuel economy.[67] Under development at Texaco since the late forties, the TCCS (Texaco Controlled-Combustion System) utilized a coordinated arrangement of air swirl, fuel injection and positive ignition (Figure 5). Although emission control was not a design



SOURCE: E. M. Withjack, Stratified Charge Engines, Dept. of Transportation, Report No. DOT-TSC-OST-75-56, January 1976, p. 3-7.

FIGURE 4. RUSSIAN NILOV ENGINE
Honda Motor Company



SOURCE: E.M. Withjack, <u>Stratified Charge Engines</u>, Dept. of Transportation, Report No. DOT-TSC-OST-75-56, January 1976, p. 2-16.

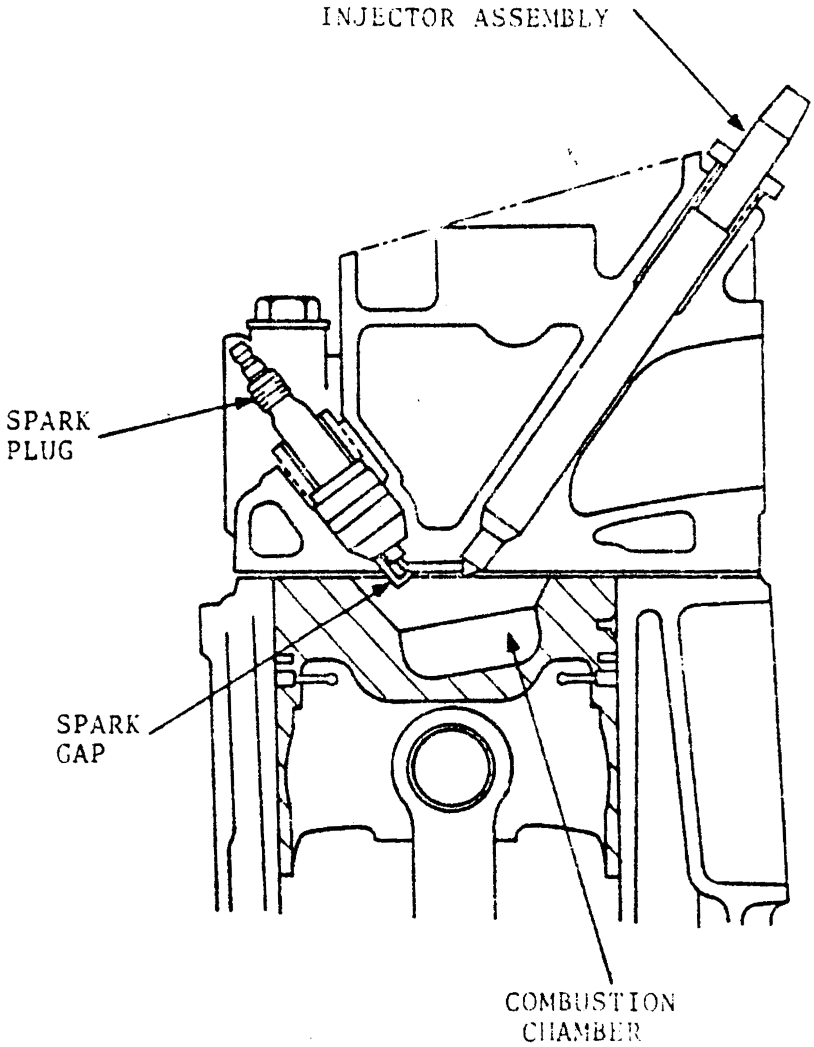
FIGURE 5. TEXACO TCCS ENGINE
Honda Motor Company

objective, Texaco, in 1973, built an experimental TCCS engine, fitted with a catalytic converter, which could meet the '76 federal standards for emissions.[68] Texaco continued research on the engine into the early seventies and, in 1974, completed a licensing agreement with a U.S. engine manufacturer for potential commercial use.[69]

In the late fifties, Ford Motor Company's engineering and research staff developed and patented the PROCO (Programmed Combustion) stratified charge engine, developed to minimize exhaust emission without drastic reductions in fuel economy[70] (Figure 6). Ford built a successful laboratory engine in 1960. It is interesting to note that, in the development of the PROCO system, Ford dismissed designs utilizing one or more carburetors with a divided chamber like Honda's CVCC engine, preferring an open-chamber, fuel injection system.[71] Instead of a prechamber fed by a separate carburetor valve, the open-chamber stratified charge engine like Ford's PROCO or Texaco's TCCS relies principally on air motion within a single main combustion chamber. Moving air is coordinated with an injection of fuel to achieve a spatial variation of fuel mixture.[72] Fuel consumption of the PROCO was expected to be 18-25 percent better than a conventional engine, but with an appreciable loss of power output. Aside from this, Jack Collins, head of Ford's engine research, has said that the cost of the PROCO engine will be 5-15 percent higher than a conventional engine.[73] Despite these problems, Ford continued developing the PROCO system through the early and mid-seventies and, in 1975, estimated that preproduction work could be completed by 1980.[74]

Another stratified charge engine carried to a high state of development was Curtiss-Wright's adaption in 1962 of a Wankel-type rotary engine to a stratified charged diesel engine. Like the PROCO and TCCS engine, Curtiss-Wright's system employed fuel injection nozzles adjacent to the spark plugs rather than carburetor valves. As of the early seventies, this engine was still in the development stage.[75]

Other highly developed stratified charge engines existed in the sixties, but were not found as easily in public literature, as were the PROCO, TCCS, and Curtiss-Wright engines. These lesser known experimental engines include the Broderson Conta and Heintz ram—straticharge engines, both developed and built in the early sixties. These engines used fuel injection into the precombustion chamber instead of carburetors. The Heintz engine was extensively tested in a Chrysler V-8, but was abandoned in the late sixties because of appreciable power loss. The Conta engine ran well under load on extremely lean mixtures, but was given up because of its severe noise problem.[70]



SOURCE: E. M. Withjack, Stratified Charge Engines, Dept. of Transportation, Report No. DOT-TSC-OST-75-56, January 1976, p. 2-2.

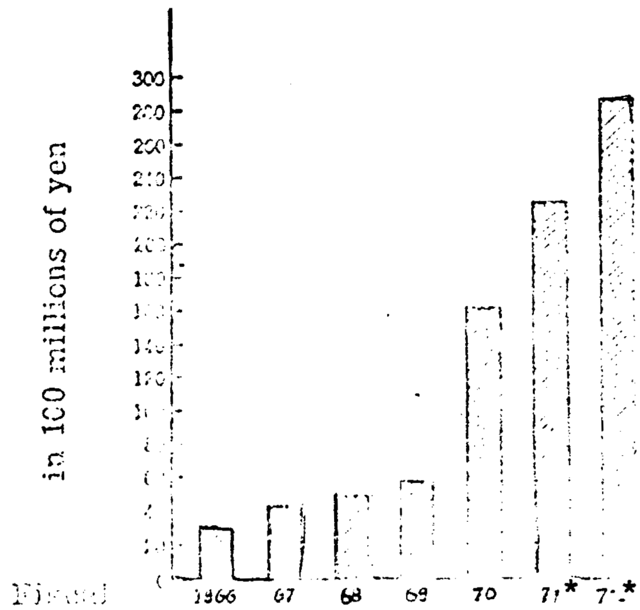
FIGURE 6. FORD PROCO ENGINE
Honda Motor Company

Most of these early engines were developed to improve engine fuel economy. None of them made it into mass production. They suffered from a variety of common problems: the inability to create a consistent charge stratification at all speeds; the inevitable complications of adding direct cylinder injection to a spark ignition engine; and high variability in their level of HC, CO and NO_x emissions. Ford's PROCO engine, in particular, demonstrated heavy increases in fuel consumption and complications in its fuel injection system. Moreover, Ford admitted that the PROCO showed severe durability problems.[77] Lastly, most of the experimental stratified charge engines appeared far too costly. (See Appendix for a breakdown of estimated manufacturing costs for various stratified charge power plants.)

1.4.7 Honda's Development of a Stratified Charge Engine

While none of these experimental engines became production realities, Honda's engineers saw in them theoretical possibilities not only for increased fuel economy, but for practical, reliable emission control.[78] To Honda's engineers, the stratified charged, internal combustion engine in theory offered the most immediate and best alternative to extensive use of catalytic reactors and to untried and unproven alternative engines.[79] The stratified charge engine appeared the most versatile, efficient, and clean of the power plants that could be developed and mass-produced in a relatively short time.[80] Using the available theoretical material as their starting point, Honda's engineers designed and built a prototype stratified charge engine. In this early engine, they focused on modifying the chamber geometry in order to achieve the proper combustion characteristics. In fact, chamber design--the configuration of the combustion chambers and the connection between the prechamber and main cylinder--was the focus of Honda's subsequent experimental work and the key to the engine's success.[81] Most engineers working with stratified charge engines a decade earlier saw, at least theoretically, the possibilities for fuel economy and emissions control. It was Honda, however, that discovered the design parameters that allowed the engineer to accurately control the combustion process and, hence, the output of unwanted emissions (Figure 7).

By the time the U.S. had established the 1970 Clean Air Act setting stringent reductions for HC, CO, and NO_x emissions for 1975 model year cars, Honda's development of the CVCC was well under way. Seventy percent (about 560 people) of Honda's total R&D personnel was working on some aspect of the CVCC engine, so the research subsidiary postponed other commercial developments and ideas for the time being. Honda's manpower commitment to the CVCC was larger than both



* est. plan

SOURCE: H. Uneo and H. Muto, The Automobile Industry of Japan, Japanese Economic Studies, Fall 1974, p. 32.

FIGURE 7. JAPAN'S AUTOMOBILE MANUFACTURERS' TOTAL POLLUTION CONTROL RESEARCH EXPENDITURES -- 1966 TO 1972
Honda Motor Company

Nissan's and Toyota's total research staff working on anti-pollution development. Moreover, while Nissan and Toyota each spent $22 million in total anti-pollution research outlays in 1970, Honda was spending approximately $25 million on CVCC developments (Table 8). Honda listed this money as expenditures for anti-pollution or auto emissions research (Appendix 8).

In general, during this period, the Japanese automobile industry, which exported a significant percentage-11 percent of its total output to the U.S., began steadily increasing its R&D efforts to control car exhaust gases.[82] In 1970, total industry anti-pollution research costs climbed to approximately $76,750,000 or an amount equal to 10.7 percent of total industry fixed investment, up 500 percent since 1968 (Table 9).

Honda, aware of commercial possibilities of the new engine, resisted the intense pressure on Japan's smaller auto companies to reorganize and to tie up with American firms. Moreover, Honda's strong worldwide position in the motorcycle market stregthened the company's overall position, so that it could be indifferent to merger forces operating on Japan's small automobile manufacturers. The late sixties and early seventies marked a period of steady import and capital liberalization in Japan's economy; and Japan's smaller automakers in order to survive the new threat from abroad looked to the U.S. and Europe for technical and marketing help. Mitsubishi, in return for the chance to sell its Colt sub-compact in the U.S., allowed Chrysler to take 35 percent of its stock. Toyo Kogyo agreed to collaborate with Ford on an automatic transmission plant, using Detroit's know-how. In the exchange, Ford bought 20 percent of Toyo Kogyo with the declared intention of eventually increasing its share to 35 percent. Isuzu, the smallest of the Japanese companies with only 3 percent of the domestic market in 1970, negotiated with GM to sell its pick-up trucks and small diesel engines abroad, as well as to establish jointly an automatic transmission plant. Due to its technical competence and marketing abilities, honed by its success in the world motorcycle business, Honda managed to avoid the mergers and bargaining with Detroit's Big Three.

1.4.8 EPA's 1972 Test

By summer 1972 Honda had built a prototype CVCC engine. The research and development work had taken approximately three years. From start to finish, there was no outside assistance and no outside consulting on the project.[83] Honda immediately sent three prototype cars, equipped with the new CVCC engine to the Environmental Protection Agency (EPA) for testing in October. The EPA had recently established U.S. emission standards for 1975 model year cars (0.41 HC/3.4CO/3.1 NO_x). The prevailing view in the automobile industry at this time was that satisfying both requirements of low

TABLE 8

R&D SPENT ON POLLUTION CONTROL IN 1970

Honda Motor Company

Firm	Amount	% of Total Fixed Investment	Personnel
Toyota	$22 million	9.4	280
Nissan	$22 million	12.3	
Toyo Kogyo	$7.2 million	17.3	300
Mitsubishi	$4.1 million	8.5	180
Isuzu	$2.7 - 4.1 million	6.6 - 10.0	200
Honda	$25 million (for CVCC engine development)		580

Source: H. Uneo and H. Muto, The Automobile Industry of Japan Japanese Economic Studies, Fall 1974, p. 32.

pollution and acceptable fuel consumption and performance was impossible with current technology. The three prototype cars were found to have the lowest emissions of any gasoline fueled automobile, without exhaust treatment, ever tested by EPA[84] (Table 9). In the test, the EPA reported no smoke, odor, or noise problems from the new engine.[85]

The EPA's 1972 test of the CVCC demonstrated the possibility of meeting the 1975 federal standards without the use of add-on devices or drastic switches to untried, unproven, and costly alternative engines. Two months after the EPA test, the National Academy of Sciences, in its report on the federal emissions standards, had this to say about Honda's CVCC:

> As compared with the catalyst—dependent system, now being emphasized by the major manufacturers, (the CVCC System) offers the promise of lower initial purchase costs, greater durability in service, and significantly greater fuel economy.[86]

1.4.9 Fuel Economy, Power Output, Modification Problems

After the EPA's 1972 test of the CVCC, Detroit was quick to criticize the engine and minimize its importance for the U.S. auto industry. Ford Motor Company, in a letter to the National Academy of Sciences in January 1973, pointed out that the performance data on the CVCC were only for light vehicles. Its engineers felt that the CVCC could not be adapted successfully to the big V-8s. Furthermore, the letter said the system's carburetor dashpot action might limit the capacity for vacuum accessories like power brakes. Finally, Ford's letter mentioned that the CVCC probably could not meet the U.S. 1976 NO_x standards.[87]

Detroit engineers argued, moreover, that all stratified charge engines including the CVCC had considerable drawbacks in fuel economy and power output. Engine specialists from both Ford and GM claimed that the engine consumed 25 percent more fuel than a conventional engine and suffered a 25 percent drop in power output.[88] They attributed the loss of power to the slower burning and lower temperature in the main combustion chamber. Stretching out the combustion process, they said, beyond the piston's midway-point on the expansion stroke means less energy against the piston and, hence, less torque.

TABLE 9.

EPA'S 1972 TEST OF HONDA CARS EQUIPPED WITH CVCC ENGINE

(IN GRAMS/MILE)

Honda Motor Company

	HC	CO	NO_x
low mileage	0.21	1.96	0.81
hi-mileage	0.26	2.57	0.98
1975 Statutory Federal Standards	0.41	3.4	3.1
* 1975 Japanese Standards	0.25	2.1	1.2
* Reciprocating Engine Average	3.9	21.0	3.2
U.S. 1976 Standards	1.50	15.0	2.0

SOURCE: Car and Driver, February 1975, p.55.
Popular Science, April 1973, p.86.

* H. Uneo and H. Muto, The Automobile Industry of Japan
Japanese Economic Studies, Fall 1974, p. 68.

Detroit engineers also felt that the CVCC presented difficult conversion problems for the U.S. auto industry.[89] It was questionable whether or not Honda's engine, with a cylinder bore equal to 2.76 inches, could be adapted successfully to V-8s with 4-inch bores or more. Also, the CVCC system's valve gear--a simple overhead camshaft with a basic rocker-arm arrangement to each of the three valves per cylinder--differed substantially from Detroit's V-8s which used pushrods from a camshaft in the block. In other words, Detroit said, a change to CVCC technology amounted to not a simple modification, but a substantial and costly redesigning of Detroit's automobiles.[90]

An EPA official initially backed up Detroit's contention about the CVCC's fuel consumption.[91] But, while noting that the engine burned 20 percent more fuel than other cars in its weight class, he qualified this fact by pointing out the CVCC's superior power-to-weight ratio which more than offset the rise in fuel consumption. The CVCC was rated at about 70 hp as compared to other cars of similar weight in the 50 to 59 hp range. This meant that the CVCC delivered essentially the same power and fuel economy as the engine it replaced. Consequently, the CVCC, the EPA official felt, meant no significant trade-off between clean operation, and power and fuel economy.

Honda further claimed that not only did the CVCC represent no trade-off between emission control and performance, but that the engine, once Honda's engineers had had the chance to work out the initial problems that attend any new technology, eventually would result in considerable fuel economy. Honda's claim later proved spectacularly correct: from 1974 to 1977, the EPA rated the Civic CVCC as the car with the highest estimated gas mileage of the 300 models it had tested (Table 10).

Later tests refuted Ford's argument that the CVCC could find no application in Detroit's larger cars. Initial EPA tests were conducted on 2-liter (119CID) 4-cylinder engines in Honda Civics. Honda refitted with CVCC heads two Detroit engines--a 140 CID 4-cylinder GM Vega and a 350 CID V-8 Chevrolet Impala. The CVCC engines were not equipped with EGR, catalysts, or air pumps. The data indicated that the CVCC GM-Vega could meet the original 1975 federal emission standards with a fuel economy improvement of 9 percent. Test results for the CVCC 350 CID V-8 Impala also showed emission levels below the federal standards with marginal gains in fuel consumption (Table 11).

Honda, which had developed the CVCC engine with the intention, in part, of selling the technology, insisted over Detroit's criticisms that the CVCC required no significant retooling and, actually, would save money. Conversion to the

TABLE 10

FUEL ECONOMY OF PASSENGER CARS USING HONDA CVCC ENGINE -- 1974 TO 1977

BASED ON EPA MILEAGE TESTS

Honda Motor Company

Car Model	Year	Inertia Weight	Transmission	City	Highway
Prototype (76 CID)	1974	2000	M4	25	35
Civic (76 CID)	1975	2000	M4	28	38
		2000	M5	28	42
Civic (76 CID)	1976	2000	M4	28	41
Civic (91 CID)	1976	2000	M5	31	44
	C-76	2000	M4	32	42
	C-76	2000	M5	31	44
Civic (76 CID)	1977	2000	M4	28	43
Civic (91 CID)	1977	2000	M4	39	50
	C-77	2000	M4	35	46
Accord (98 CID)	1977	2250	M5	38	48
	C-77	2250	M5	33	47

SOURCE: A.F. Burke, "The Moving Baseline ot Conventional Engine-Powered Passenger Cars," SAE Paper 780347, February 1978, p. 8.

TABLE 11

EMISSIONS AND MPG FOR CONVENTIONAL AND CVCC ENGINE

Honda Motor Company

EMISSIONS FOR CONVENTIONAL AND CVCC VEGA

Configuration	HC	CO	NO_x	MPG
Conventional	2.13	10.6	3.8	17.2
CVCC	0.26	2.9	1.18	17.9

Note: 140 CID at 2500 lb I.W.

EMISSIONS FOR CONVENTIONAL AND CVCC 1975 IMPALA

Configuration	HC	CO	NO_x	MPG	Source
Conventional	1.56	19.33	2.42	10.5	Honda
CVCC	0.19	2.85	1.57	10.9	Honda
CVCC	0.23	2.9	1.7	11.2	GM (5 tests)

Note: 350 CID V-8 at 5000 lb inertia weight.

EMISSIONS FOR CVCC HONDA AND CVCC IMPALA

Configuration	HC	CO	NO_x	MPG
Honda	0.21	2.06	0.96	21.4
Impala	0.23	2.9	1.7	11.2 (5 tests)

Note: CVCC Honda 2000 lb I.W.
CVCC Impala 5000 lb I.W.

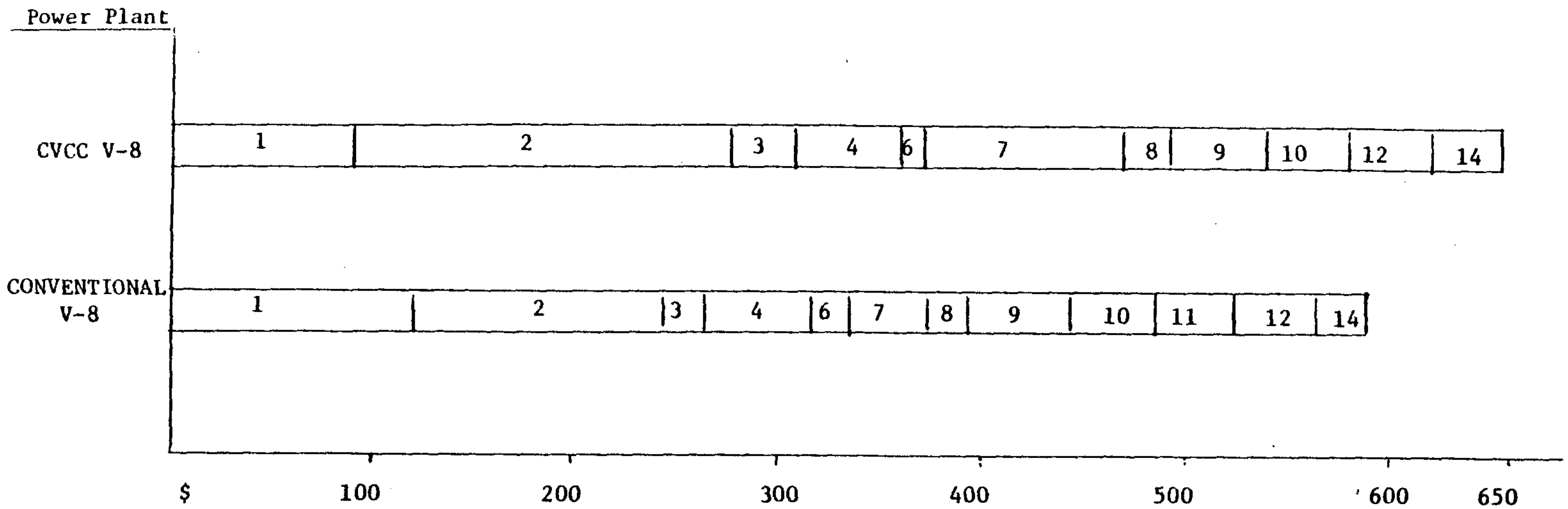
SOURCE: E.M. Withjack, <u>Stratified Charge Engines</u>, Dept. of Transportation, Report No. DOT-TSC-OST-75-56, January 1976, pp. 3-9 and 3-10.

CVCC technology necessitated no major changes in the conventional engine block, pistons, or crankshaft.[93] The minor changes needed in the cylinder head, along with the extra carburetor and additional parts needed to open and close the second intake valve on each cylinder, added very little to the basic cost of the engine. The National Academy of Sciences estimated that a CVCC V-8 would cost only $60 more to produce than would a conventional gasoline V-8 power plant[94] (Figure 8). For a 1200cc CVCC, one writer estimates the price to the consumer to be about $170 more than the price with a conventional 65-hp engine.[96] Honda, when it eventually introduced the CVCC engine into the U.S. market in 1975, estimated that the list price of its Civic CVCC automobile would be $100 to $200 higher than a Civic with a conventional engine.[96] This added cost, however, was more than offset by the savings from not using add-on devices. It was estimated that emission control devices would cost the consumer about $350 per car by 1973.[97] The high cost was due not only to the materials and special servicing--converters tended to foul and to break down easily--but to the estimated 10-15 percent decrease in fuel economy.[98] Thus, Honda claimed the CVCC potentially offered the consumer a $180 savings in overall cost.

While there was little data available from U.S. manufacturers on converting to Honda's CVCC engine, Ford, which had evaluated the CVCC for meeting a 2.0 gm/mile NO_x standard, estimated a cost of $150 million for conversion of its 140 CID engine line and $160 million for changing the 400 CID engine line.[99] Honda realized, though, that the biggest obstacle to Detroit's quick adoption of the CVCC technology was not only the problems peculiar to the CVCC itself, but the millions of dollars that Detroit already had invested in catalytic converter facilities and materials. Another problem was that Honda's breakthrough came at a time when Detroit already had turned to Germany's Wankel engine. By 1973, GM, Ford, Chrysler, and AMC had taken steps toward use of Wankels in future-year car models.[100]

1.4.10 Licensing of the Technologies

Honda made its CVCC engine know-how available on a non-exclusive basis.[101] Honda had patented the essential features of the engine: the CVCC's exact configuration; the carburetion system; the auxiliary chamber; and the connecting combustion chamber device. Moreover, it held numerous patents and licenses, 280 altogether, on all of the engine's supporting equipment like automatic temperature control devices, intake and exhaust manifold apparatus, and fuel injection control devices and carburetion devices.



Manufacturing Cost Breakdown

1. CYLINDER BLOCK
2. CON-RODS, CRANKSHAFT, VALVE GEAR, FLYWHEEL ETC.
3. PISTONS
4. CYLINDER HEAD(S)
5. CONTROL GEAR BETWEEN EGR, THROTTLE, DISTRIBUTOR AND INJECTION PUMP
6. MANIFOLDS & HEATING PIPEWORK ETC.
7. EXHAUST REACTOR AND/OR CATALYST
8. IGNITION DISTRIBUTOR, COIL, PLUGS
9. EGR VALVE AND PIPEWORK
10. OTHER EMISSION CONTROL GEAR: EVAP. CONTROL, P.C.V., INTAKE HEATER, TRANSMISSION CONTROLLED SPARK, SPARK ADVANCE CONTROL, ANTI-DIESELING SOLENOID, ETC.
11. AIR PUMP
12. STARTER MOTOR, ALTERNATOR VACUUM PUMP, HYDRAULIC PUMP
13. TURBOCHARGER
14. CARBURETTOR AND/OR INJECTION PUMP, PRIMARY INJECTORS, SECONDARY INJECTORS

* "Cost estimates information was taken mainly from 'in house' unpublished sources and from surveys carried out by the National Academy of Sciences (NAS) into engine production costs. An allowance was made for inflation when information from previous studies was used and the bar chart (above) gives the estimated production costs (1975 U.S. dollars) for each power plant involved."

SOURCE: A Study of Stratified Charge for Light Duty Power Plants, U.S. Environmental Protection Agency, Reference No. EPA-46/3-74-011A, Vol. III, October 1975, p. 23-24.

Above quotation from this study, p. 23.

FIGURE 8. ESTIMATED PRODUCTION COSTS OF CVCC V-8 COMPARED TO A CONVENTIONAL V-8*
Honda Motor Company

Despite their early demurrals, both Ford and GM were discussing possible business associations with Honda by October 1972 and, in that winter, sent engineers to visit Honda R&D.[102] By July 1973, Ford, Isuzu, and Chrysler had entered into some form of licensing agreement with Honda for access to its CVCC technology. Basically, these agreements were of two kinds. To one group, Honda granted wide-ranging rights to develop, build and sell the CVCC engine. This group included Ford and Toyota.[103] To a second group, Chrysler and Isuzo Motors, Honda sold more limited agreements for access to the CVCC technology.[104]

Ford reportedly paid $3 million for the technology and rights and, furthermore, agreed to substantial royalties.[105] Ford's general manager of Engine Division, Thomas J. Ferheny, explained Ford's purchase of CVCC technology and production rights: "We're not really, never were, a nation of inventors... America's success is as much a matter of exploitation as it is innovation."[106] Ford had no immediate plans for commercial production of the CVCC but its president, Lee A. Iacocca, said that his company could build a half million engines for its 1977-model cars.[107] With regard to GM, it is interesting to note that in May 1973, GM's president, Edward Cole, revealed that GM had expressed interest in ordering 400,000 CVCC engines from Honda for the 1975 model year, Honda replied that it had neither the "interest nor capacity" to provide them.[108]

1.4.11 Market Introduction of CVCC--Japan and U.S.

As expected, the introduction of the CVCC engine contributed substantially to strengthening Honda's position in the sub-compact car market both at home and abroad. At the end of 1971, Honda was a weak fourth in the industry with only 7.77 percent of the market and less than 5 percent of its export sales due to automobiles[109] (Table 12). The next year Honda claimed only 6.2 percent of Japan's total production of four-wheeled vehicles--still far behind the giants, Toyota and Nissan, and the smaller Toyo Kogyo.

Honda's domestic market share changed dramatically over the next five years with the introduction in December 1973 of the sub-compact Civic CVCC. The car immediately was well accepted, and demand quickly outran supply.[110] The excellent domestic market response continued through 1974. During this time, Honda almost doubled its production of sub-compact passenger cars from 129 to 209 thousand units and succeeded in increasing its domestic market share of total four-wheel vehicle production from 5.6 percent to 7.7 percent (Table 12).

TABLE 12

MARKET SHARE OF JAPAN'S AUTO MANUFACTURERS -- 1971

Honda Motor Company

Firm	Market Share
Toyota	31.5
Hino	.8
Daihatsu	5.7
Nissan	25.5
Fuji Heavy Industries (Auto)	4.0
Toyo Kogyo	9.2
Mitsubishi Heavy Industries (Auto)	7.2
Isuzu	3.3
Honda	7.7
Suzuki	5.1
Total	100.00

SOURCE: E.J. Kaplan, Japan -- The Government-Business Relationship, Dept. of Commerce., February 1972, p.128.

TABLE 13

HONDA'S PRODUCTION OF PASSENGER CARS -- 1972-1977
('000)

Honda's Production of Passenger Cars -- 1972 -1977
('000)

	1972	1973	1975	1976 (Six months ended Feb. 29, 1976)	1977 (Year ended Feb. 28, 1977)
Sub-compact cars	59	129	209	294	486
Mini-cars	180	114	89	4	0
Total	239	243	298	299	486
Domestic Production Share	6.2	5.6	7.7	9.1	10.2

SOURCE: Honda Motor Company, Prospectus, December 1976, p.22.

In gauging Honda's success with the CVCC in the Japanese market during this time, it is important to take into account the crisis the rest of the auto industry was undergoing due, in part, to the 1973 oil crisis and the extraordinary increases in the price of fuel. Because of increased costs, Japanese automakers, in the fall of 1973, raised prices in the domestic market 7 to 8 percent. When they raised them again in early 1974, Honda, who by then held 9 percent of the domestic market for sub-compact and who recently had unveiled its new CVCC, decided against price increases. By mid-1974, the commercial success of this strategy was apparent. The domestic sales of Nissan and Toyota, the industry leaders, were off by 40 percent from the previous years.[111] Honda, by contrast, during this same period registered a 76 percent increase in sales over the previous year.[112] Part of this increase resulted undoubtedly from Honda's ability to hold down the price of its automobiles for Japan's cost conscious consumers. The consumer popularity of the fuel efficient, clean running CVCC also contributed substantially to strengthening Honda's sales.

By the time Honda entered the American market in 1974 with its CVCC Civic, Japan's penetration of the U.S. automobile market was extensive (Appendices 4 and 5). In general, Japan's automobile exports grew spectacularly in ten years. From 1961 to 1971, exports increased about 113 times (from 11,500 to 1,300,000 units). Japan's total passenger car exports to the U.S. were 654,000 units, 6.7 percent of total car sales in the U.S. (about 10.9 million units) and 44.6 percent of U.S. imports of foreign cars.[113]

1.4.12 <u>Distribution Strategy in U.S.</u>

By mid-1974, Honda prepared to market the Civic CVCC in the U.S. and decided on a distribution strategy. Earlier that year, Honda had turned down Ford's offer to sell the Civic CVCC in the U.S.--an exclusive arrangement similar to Chrysler's deal with Mitsubishi for selling the Dodge Colt. It decided, instead, to establish its own distribution network, utilizing as much as possible its existing U.S. motorcycle and automobile distributors and setting up new dealerships.[114] By late 1974, Honda had 420 dealers, many of which were "dual" agencies handling other makes, thus giving Honda extra exposure.[115]

In general, Honda decided to go slowly, developing the U.S. market over a long period of time.[116] Honda's limited production capacity partly explained this decision. The company had sold 43,000 Honda Civic CVCCs in the U.S. in 1974. With expansion of its production facilities, it estimated that it could sell 125,000 to 150,000 automobiles the next year.[117] Yet, it was having trouble meeting Japan's domestic demand.[118] Moreover, Honda's plans for major expansion of its automobile manufacturing facilities met with strong government resistance and capital problems. Hoping to curb Japan's galloping inflation, the Japanese government in 1974 initiated restrictive credit policies designed to halt capital plant outlays. Those policies limited the size of Honda's new plants.[119]

In 1975, Honda introduced the new Civic CVCC series, a two-door, hatchback, and four-door sedan with either a 1,200 c.c. or 1,500 c.c. CVCC engine. Despite the recession in both Japan and U.S., sales of the Civic CVCC remained high, running about 10 thousand per month in California alone.[120] U.S. demand for small cars in general was strong. Imported compacts and sub-compacts accounted for 1.7 million automobile purchases in 1973 and 1.6 million in 1975--capturing 20 percent of the depressed U.S. market.[121]

1.4.13 Commercial Success in U.S.

With U.S. sales of 102,389 units, the Honda Civic moved to fourth place among U.S. import sales in 1975, up from 12th place in 1974 and a sales increase of 137.5 percent over the previous year (Table 14). The Civic's consumer appeal was understandable. The car offered the lowest sticker price of any car in the U.S. ($2,729) and, equipped with the CVCC engine, demonstrated the best gas mileage (up to 44 mpg) while operating well within the EPA's emission standards.[122]

In 1976, with sales of U.S. automobiles on the decline, Honda continued to expand its export business, with sales of 151,000 Civics in the U.S., up 36 percent from the year earlier. Sales increased in Europe and Canada, as well, and Honda's total export sales of 300,000 units surpassed its domestic sales of 246,000. During the year, Honda introduced the Accord, a larger, sedan, fitted with the CVCC engine. Honda's confidence in the consumer appeal of this model was evident by the fact that it marketed the new Accord simultaneously in Japan and the U.S.--the first time a Japanese motor vehicle manufacturer marketed a new product in both the domestic and foreign markets. Also in 1976, Honda increased its production capacity to 600,000 units and, in the U.S., added 110 dealers to its distribution network.

The full impact of Honda's success with the CVCC was felt by 1977. In the period between 1972 and 1977, Honda had increased its production of sub-compact cars by over 900 percent, had built up a substantial export market for over half its total automobile production, and had captured 10.2 percent of Japan's domestic market. In addition, it

TABLE 14

U.S. RANKING OF FOREIGN CAR SALES

Honda Motor Company

U.S. Ranking of Foreign Car Sales

	U.S. sales		Percent
	1975	1974	change
Toyota	283,909	238,135	+ 19.2%
Volkswagen	267,718	334,515	− 20.0
Datsun	263,192	189,026	+ 39.2
Honda	102,389	43,119	+137.5
Fiat	100,511	72,029	+ 39.5
Mazda	65,351	61,190	+ 6.8
Colt	60,356	42,925	+ 40.6
Volvo	59,408	52,167	+ 13.9
Capri	54,586	75,260	− 27.5
Mercedes	42,093	35,294	+ 19.3
Subaru	41,587	22,980	+ 81.0
Opel	39,730	59,279	− 33.0
BMW	19,419	15,007	+ 29.4
British Leyland	70,839	54,161	+ 30.8

SOURCE: Business Week, January 26, 1976, p. 32.

ranked third among Japan's nine auto manufacturers in terms of production units, fourth in the U.S. in unit sales of imported passenger cars, eighth in the U.S. based on unit sales of all cars, and first in Canada in imported passenger cars.[123]

Honda's Civic model became a sensation of sorts. It was named "Car of the Year" by Japan's auto magazine, Motor Fan, 1972 through 1974, and "Import Car of the Year" by the U.S. magazine, Road Test. The larger Accord was named "Car of the Year" by Motor Fan magazine in 1976. Since 1973, these models were equipped with the CVCC low-pollution engine. Moreover, CVCC-equipped Civics were rated in 1976 and 1977 by the EPA as automobiles with the highest estimated gas mileage. The CVCC-equipped Accord was rated by the same agency as the automobile with the fourth highest estimated gas mileage in 1977.[124]

Since the introduction of the CVCC engine, Honda has relied heavily on the U.S. market for its home-plant output. Indeed, it was the front-runner among Japan's automakers in terms of percentage of its cars going to the U.S.--28 percent of its world-wide sales volume going there.[125] This meant pricing in the U.S. was far more crucial to Honda's future than for companies with a broader world-wide market. Accordingly, while other Japanese companies steadily raised their prices throughout the seventies, Honda's prices remained the same. Honda's dependence on the U.S. market also meant that there was a strong incentive for it to move there. In mid-1977, Honda announced that it would begin building motorcycles in an Ohio facility. There was strong speculation that an automaking plant would soon follow.[126]

1.4.14 Other Automakers

Honda's development and production of the CVCC engine has spurred the development of other advanced stratified charge systems. Indeed, the design for Porsche's SKS (Schichtlasle-Kammar-System) came directly from Porsche's study of the CVCC engine. Two Porsche engineers, Dusan Gruden and Karlheinz Lange, studied CVCC engine theory and applied the same principles to a mechanically simplified system with lower production costs.[127] Toyota's TTC-L system (Toyota Total Clean-lean) was developed after Toyota purchased from Honda CVCC technology rights.[128] Fiat, after news of the CVCC reached Italy, undertook a development program for a stratified charged engine. After Fiat decided that its designs infringed on Honda's CVCC patents, the company signed an agreement in 1974 with Honda for rights to CVCC technology.[129] Mercedes-Benz, though it had not picked up Honda's technology, developed its own system, with prechamber injection and an unscavenged chamber.[130] GM, VW, Mitsubishi, Nissan, British Leyland and Daimler-Benz also are developing stratified charged engines.[131]

SUMMARY HIGHLIGHTS

Role of Advocate / Corporate Personality

Honda Motor Company had an industry-wide reputation for being an engineering company, dominated by its engineer founder, Soichiro Honda, who played a substantial advocacy role in the development of the CVCC engine.

Role of Market Pull / Role of Regulation

By the mid-sixties, it became obvious that Honda needed a significant innovation if it were to survive and compete successfully against larger Japanese automakers. Pollution control regulation as well as rising fuel costs both in the U.S. and abroad forced automakers to consider possible alternatives to the conventional gasoline engines. In this context, Honda saw a ready market for a low-polluting, fuel efficient engine.

Sources of the Innovation

A number of experimental stratified charge engines had reached high states of development previous to Honda's work. Moreover, theoretical work had been carried out for many years on the fifty-year old concept of charge stratification. Honda's engineers were aware of this work.

Gestation Period / Resources

In a four year period from 1968 through 1972, Honda designed, tested, mass-produced and marketed the CVCC engine. During this time Honda committed a substantial portion of its R&D funds -- $50 million -- toward the CVCC's research and development. While the initial work was done by two engineers, by 1969 seventy per cent or approximately 560 people of Honda's total R&D personnel were working on some aspect of the CVCC engine.

Barriers to Adoption

There were no significant barriers to adoption. Manufacturing costs were competitive to other engines of similar output equipped with pollution control devices. There was some doubt, however, about the application of the CVCC to larger displacement engines like Detroit's V8's. Pollution standards offered no immediate problem; when introduced in in 1973, the CVCC met the 1975 federal emission standards for HC, CO, and NO_x. There was some doubt as to whether or not the CVCC engine could meet the 1978 NO_x standards without the use of add-on devices. There were no major technical problems: the CVCC required no significant retooling since conversion to CVCC technology necessitated no major changes in the conventional engine block, pistons or crankshaft.

Current Status

Although Honda sold the technical rights to CVCC technology to a number of U.S. and foreign firms, as yet only Honda markets cars -- its sub-compact Civic and Accord -- equipped with 1500cc and 1200cc CVCC engines. Since their introduction into the American and Japanese markets, demand for the cars has been very strong. The CVCC's success has substantially strengthened Honda's market position.

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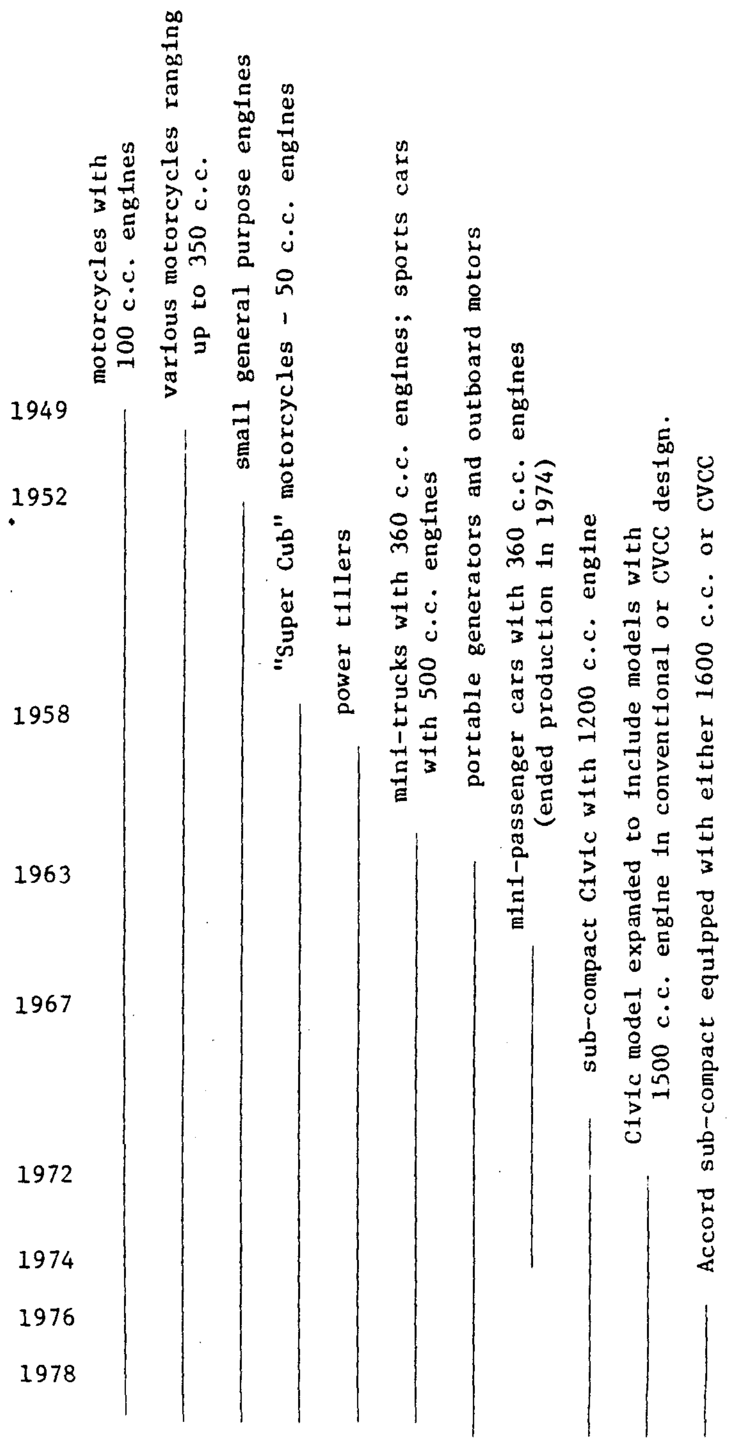
APPENDIX 1

HISTORY OF HONDA'S PRODUCT LINES

Honda Motor Company



APPENDIX 2

HONDA'S RESEARCH AND DEVELOPMENT EXPENDITURES -- 1964-1977

Year *	Total $ ('000)	R&D As % of Total Net Sales ***	$ for Automotive Emissions Control ('000'000) **	Number of Employees in R&D
1964	5,707			
1965	6,811			
1966	8,463	2.3		821
1967	8,893	2.3		723
1968	10,489	2.0		754
1969				825
1970	17,400	2.0		
1971	23,800	2.1		
1972	29,208	2.2	13.8	
1973	36,028	2.5	32.9	
1974	46,290	2.6	36.7	
1975	49,700	2.5	43.3	
1976	67,138	2.6	45.0	1500
1977	71,357		49.5	1600

SOURCES: * 1964-1968 figures from Honda Motor Company Prospectus, January 14, 1969. Figures include general and administrative costs.
Honda Motor Company Prospectus, July 26, 1977, p.7.

** Honda Motor Compnay Prospectus, Dec. 1976, p.32.

*** Sales figures from supplement to Honda Motor Company Prospectus, July 1977.

N.B. R&D figures include research, engineering, reliability inspection, testing, facilities, and tools.

APPENDIX 3

HONDA'S MOTOR VEHICLE PRODUCTION

Honda Motor Company

Year	* Total Production of Four-wheeled Vehicles	** Total Production of Passenger Cars	*** Production of Sub-compacts	Production of Mini-cars
63				
64				
65	53,000	9,000		
66	58,000	3,000		
67	149,000	87,000		
68	319,000	186,560		
69	364,132	232,704		
70	392,985	276,884		
71	308,578	235,246		
72	330,569	235,248	59,000	180,000
73	355,016	256,962	129,000	114,000
74	428,809	316,012	209,000	89,000
75	413,753	328,107	295,000	4,000
76	560,075	473,597	435,000	0
77		776,412		
78				

SOURCES: *1965 - 1968 figures Motor Vehicle Statistics of Japan, 1978 p. 10-11.

1969 -1976 figures from World Motor Vehicle Data 1977, MVMA, Detroit, Michigan 1977, p.10.

**Ibid., p.35.

***Honda Motor Company Prospectus, December 1976, p.22.

APPENDIX 4

HONDA'S SALES AND EXPORT OF PASSENGER CARS

Honda Motor Company

Year	Total Unit Sales	Sales to U.S.*	Total Export
1964	15,529		11
1965	37,518		1,493
1966	56,808		1,815
1967	91,131		5,646
1968	259,754		18,695
1969	335,222	65	
1970	374,000	3,772	
1971	316,000	9,509	
1972	299,000	20,500	
1973	356,000	38,957	
1974	380,000	41,719	
1975	385,000	102,389	
1976	546,000	150,929	293,270***
1977**	776,412	223,633	445,186

* Figures exclude second-hand cars.

SOURCES:** Ward's Automotive Yearbook 1978, Harry A. Stack, ed., (Detroit, 1978), p. 33.

*** World Motor Vehicle Data, MVMA, (Detroit,1977), p.35.

Honda Motor Co. Prospectus, July 1977.

APPENDIX 5

BREAKDOWN OF HONDA'S UNITED STATES' SALES

Honda Motor Company

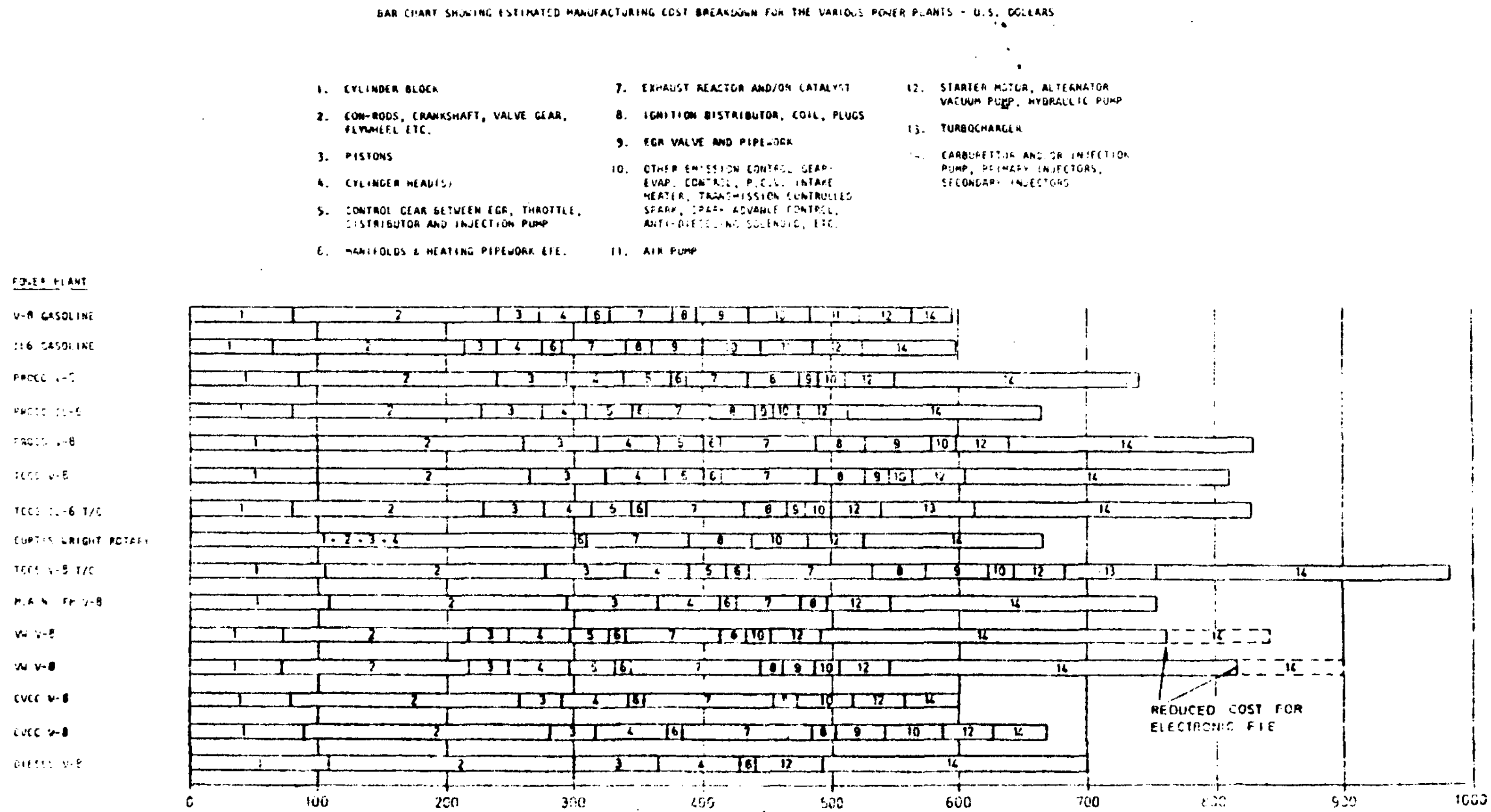
Year	Total Sales	Model	Units	% of Total	Number of Sales Outlets
1970	4,159				
1971	9,509	AN 600 Sedan	8,238	86.6	
		AZ 600 Coupe	1,271	13.4	
1972	20,500	AN 600 Sedan	8,982	43.8	215
		AZ 600 Coupe	11,518	46.2	
1973	38, 957	2-dr Sedan (4-speed)	8,765	22.5	
		2-dr Sedan (2-speed)	3,818	9.8	
		3-dr Hatchback (4-speed)	18,193	46.7	
		3-dr Hatchback (2-speed)	8,181	21.0	
1974	41,719	2-dr Sedan (4-speed)	6,383	15.3	409
		2-dr Sedan (2-speed)	2,295	5.5	
		3-dr Hatchback (4-speed)	24,865	59.6	
		3-dr Hatchback (2-speed)	8,176	19.6	
1975	102,389	Civic 1200	50,432	49.26	558
		CVCC 1500	42,311	41.32	
		CVCC Wagon	9,646	9.42	
1976	150,929	(no data)	(no data)		668
1977	223,633	Accord CVCC	75,985	34.0	
		(no data)	(no data)		

SOURCE: Ward's Automotive Yearbook

APPENDIX 6

ESTIMATED PRODUCTION COSTS FOR VARIOUS EXPERIMENTAL STRATIFIED CHARGE ENGINES*

Honda Motor Company



"Cost estimates information was taken mainly from 'in- house' unpublished sources and from surveys carried out by the National Academy of Sciences (NAS) into engine production costs. An allowance was made for inflation when information from previous studies was used and the bar chart (above) gives the estimated production costs (1975 U.S. dollars) for each power plant involved."

SOURCE: A Study of Stratified Charge for Light Duty Power Plants, U.S. Environmental Protection Agency, Reference No. EPA-46/3-74-011A, Vol. III, October 1975, p. 23-24.

APPENDIX 7

U.S. PASSENGER CAR PRODUCTION AND IMPORTS 1963 TO 1975

('000 000)

YEAR	'63	'65	'68	'69	'70	'71	'72	'73	'74	'75
TOTAL	8.0	9.9	10.3	10.0	8.6	10.9	11.2	12.2	9.4	9.1
DOMESTIC	7.6	9.3	8.8	8.2	6.5	8.6	8.8	9.7	7.3	6.7
IMPORT	.4	.6	1.5	1.8	2.0	2.3	2.4	2.5	2.1	2.4
% IMPORTS	4.8	6.0	14.4	17.6	23.7	21.0	21.5	20.8	22.7	26.0

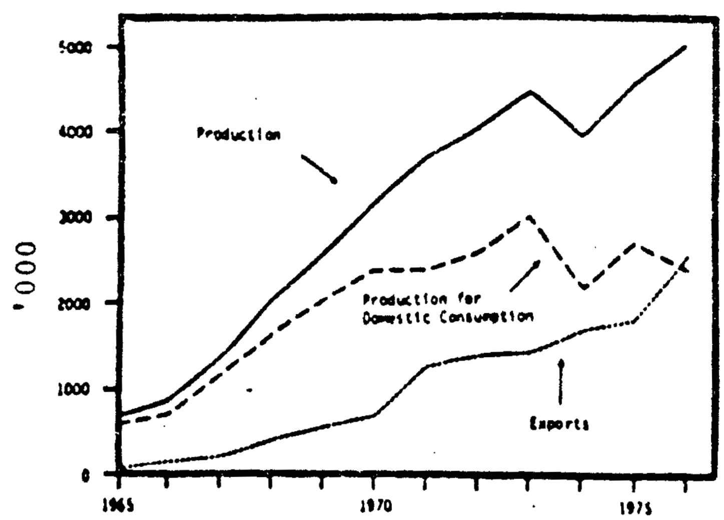
SOURCE: <u>Statistical Abstract of the United States</u>, Census Bureau, 1976, p. 593.

APPENDIX 8

JAPAN PASSENGER CAR PRODUCTION AND EXPORTS, 1965 TO 1976

Honda Motor Company

Japan Passenger Car Production and Exports, 1965 to 1976



SOURCE: Bureau of International Economic Policy and Research, Staff Economic Report, Office of Economic Research, August 1977

APPENDIX 9

HISTORIC REVIEW (1973-1978) OF FUEL ECONOMY OF CERTAIN U.S. PASSENGER CARS USING CONVENTIONAL ENGINES

Honda Motor Company

Engine: Ford L4-140 CID

Car Model	Year	Inertia Weight	Transmission	Fuel Economy, mpg City	Fuel Economy, mpg Highway
Capri (122 CID)	1973	2750	A3	17.5	
Pinto	1974	2750	A3	16.7	
Pinto	1975	2750	A3	18	26
Pinto	1976	2750	A3	21	31
	C-76 *	2750	A3	21	30.5
Pinto	1977	2750	A3	22.5	32
	1977	2750	M4	24.2	36.7
	C-77	2750	A3	22	30
	C-77	2750	M4	23	34
Pinto	1978	2750	M4	25	35
	C-78 **	2750	M4	22	31
Engine: GM L4-140/151 CID					
Vega	1973	2750	A3	18.9	
Vega	1974	3000	A3	20.1	
Vega	1975	3000	A3	21	29
Vega	1976	3000	A3	20	29
	C-76	3000	A3	18.5	27.5
Vega	1977	3000	A3	21	29
	C-77	3000	A3	21	30
Astre (151 CID)	1977	3000	A3	23	31
	C-77	3000	A3	20	27
Sunbird (151 CID)	1978	3000	A3	23	31
	C-78 **	3000	A3	23	31

* "C" refers to cars built to meet the stricter California standards.
** Equipped with a three-way catalyst.

Engine: GM L6-250 CID

Car Model	Year	Inertia Weight	Transmission	City	Highway
Chevelle	1973	3500	A3	12.8	
Nova	1974	3500	A3	15.7	
Nova	1975	4000	A3	16	22
Nova	1976	3500	A3	18	24
	C-76	3500	A3	15	21
Nova	1977	3500	A3	19	24
	C-77	3500	A3	15	22
Nova	1978	3500	A3	18	24
		Engine: Chrysler L6-225 CID			
Plymouth	1973	3500	A3	15.5	
Plymouth	1974	3500	A3	16.5	
Dart	1975	3500	A3	18	23
Dart	1976	3500	A3	18.5	23.5
	C-76	3500	A3	14.5	20
Aspen	1977	3500	A3	19.5	26
	C-77	4000	A3	16	19
Aspen	1978	3500	A3	20	27
		Engine: Ford L6-250 CID			
Mustang	1973	3000	A3	12.7	
Torino	1974	3500	A3	14.0	
Maverick	1975	3500	A3	15.5	20.5
Maverick	1976	3500	A3	17	21
	C-76	3500	A3	15.5	21

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