

Octane Requirements of 1975 Model Year
Automobiles Fueled with Unleaded Gasoline

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Octane Requirements of 1975 Model Year
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1. Summary and Conclusions, as of August 1975

Some concern has been voiced--mainly by petroleum companies and fuel additive manufacturers--that a large portion of 1975 model year automobiles will have engine knock problems when operating with unleaded gasoline of 91 RON/83 MON.

The majority of the petroleum refiners maintain that the percentage of 1975 cars satisfied with the available unleaded gasoline will be much lower than the percentages of past years (which ranged between 85 and 95% throughout the automotive industry). The concerned groups point out that too many cars will have to resort to spark retard for elimination of knock, and that this will result in a substantial loss in fuel economy. On the other hand, some petroleum companies indicate that the situation will not be much different than that of previous years, and all the major U.S. auto manufacturers affirm that there will be no serious problem.

The deposits which accumulate in the combustion chamber of the vehicles result in octane requirement increases (ORI), up to the point when the deposits reach a stabilized level. The ORI is one of the most important items for determining whether there will or will not be a problem with the octane requirements of the 1975 model year cars.

Another important point regarding octane requirements is the difference between the ratings by trained raters and ordinary drivers. It has become apparent that there is an urgent need to document and define what difference can actually be considered or tolerated between the "technical" and "customer" requirements.

On the basis of the available information, it is estimated that the percentages of 1975 model year cars satisfied with 91 RON/83 MON unleaded gasoline would be:

For ORI = 4, approximately 78% cars satisfied
For ORI = 6, approximately 62% cars satisfied
For ORI = 8, approximately 44% cars satisfied.*

* These estimates are based on data obtained through the Coordinating Research Council Informal Data Exchange Program and submitted, on December 13, 1974, to the EPA by the National Petroleum Refiners Association. However, the analysis of interim results from the CRC--dated May 14, 1975--for more recent data indicates that the percentage of cars satisfied will be higher. For these interim results, the TAEB of the EPA estimates that, for ORI = 6 and ORI = 8, the cars satisfied would be about 79% and 65%, respectively.

2. Introduction

Some concern has been voiced--mainly by petroleum companies and fuel additive manufacturers--that a large portion of 1975 model year automobiles will have engine knock problems when operating with unleaded gasoline of 91 RON/83 MON.

In this regard it has been pointed out that unleaded fuel of 91 RON/83 MON is the only unleaded gasoline that will be available at most of the retail pump outlets. This will occur because most of the gasoline companies will limit their production to satisfying only the minimum requirements of the current EPA regulations. These regulations require availability of unleaded gasoline of "not less than 91 Research Octane Number."

The concerned groups indicate that the percentage of cars satisfied with this unleaded gasoline will be much lower than the percentages of past years.* These concerned groups point out that too many cars will have to resort to spark retard for elimination of knock, and that this will result in a substantial loss in fuel economy.

The purpose of this report is to document and discuss, concisely, that information which is relevant to this potential problem concerning engine knock.

* It appears that in the past, the percentage of cars satisfied with the fuels specified by the car manufacturers has ranged between 85 and 95% throughout the automotive industry.

These estimates should be considered with caution since the data is limited. To refine the prediction, more conclusive information is needed.

If the ignition timing were retarded as needed, up to a maximum of 4° , it is estimated that the percentages of 1975 model year cars satisfied with 91 RON/83 MON unleaded gasoline would be:

For ORI = 4, approximately 95% cars satisfied
For ORI = 6, approximately 89% cars satisfied
For ORI = 8, approximately 78% cars satisfied.

In this case it is estimated that the increase in gasoline fuel consumption for the 1975 model year car population would be:

For ORI = 4, approximately 0.5%
For ORI = 6, approximately 0.8%
For ORI = 8, approximately 1.6%.

These fuel consumption increases of 0.5%, 0.8%, or 1.6% (for spark retard up to a maximum of 4° and ORI = 4, 6, or 8) for the 1975 model year car population would mean increases of approximately 0.05%, 0.08%, or 0.16%, respectively, in the total gasoline consumption of the overall car population in the USA.

Of the several oil companies contacted for this analysis, only one has reported an increase to date in customer complaints of engine knock over previous years. The company has only this year instituted a system of record keeping for customer complaints and they have no quantitative basis for comparison with previous years but the feeling was expressed that there is some increase. The increase is not judged by the company to be of major significance. Nevertheless, there is still a possibility that accumulation of miles and dry hot weather would develop audible knock in a relatively high number of cars. Certainty that this will not materialize cannot exist until enough time for mileage accumulation has passed.

Independently of the outcome of this eventual problem, the concern for the relationship between knock and octane for 1975 cars will result in some improvement of the technical evaluation of that relationship. Spokesmen from the government and the industry have pointed out the need for improving the procedure for determining the octane requirements of automobiles. Some steps are already being taken to study how this procedure can be improved. Improvements of the procedure should result in a more efficient use of engines and gasoline in the future.

3. Fundamentals Concerning Knock and Octane Requirements

3.A. Knock and the Variables which affect it.

In the automotive field, "knock" is the term generally used to signify the noise associated with the autoignition of a portion of the fuel-air mixture ahead of the normal flame front. More specifically, "spark knock" is a recurrent knock which can be controlled in intensity by adjusting the spark timing. Advancing the spark increases the knock intensity and retarding the spark reduces the intensity.

While slight knock may be desirable because it hastens the combustion process and increases the power output and efficiency, knock of high enough intensity can cause engine failure. The more likely explanation of the mechanism causing the damage is that the pressure waves associated with knock increase the rate of heat transfer to--and hence the temperature of--the susceptible parts, which causes either local melting of the material or softening to such an extent that the high local pressure causes erosion.

To understand the circumstances that cause knock, it is important to know that the most significant variables that control autoignition are the composition of the fuel and the following factors affecting the combustible mixture:

- Temperature
- Density
- Ignition delay
- Fuel-air ratio.

Thus, because of the effects of these variables, knock in the spark ignition engine:

- Increases with a lower octane rating of the fuel
- Increases with the compression ratio
- Increases with engine load
- Increases with lower engine speed
- Increases with inlet air temperature
- Increases with engine coolant temperature
- Decreases with spark retard
- Decreases with higher inlet air humidity
- Decreases for either rich or lean mixtures
- Depends on the combustion chamber design.

3.B. Knock Rating of Gasolines

The knock rating of a gasoline is found by comparing its knock response with that of a blend of "primary reference fuels" (PRF). These fuels are n-heptane with an "octane number" (ON) of 0, and isooctane with an octane number of 100. A blend containing x percent (by volume) isooctane is defined as an x octane primary reference fuel.

Several methods of knock rating of gasoline are encountered. In each of these methods a special standard engine must be run under prescribed operating conditions (of speed, temperature, etc.). The octane rating of a gasoline may have different values for different tests. Some fuels are relatively insensitive to such changes while others are quite sensitive. The two most common octane rating tests are known as the Research and Motor methods, and their corresponding ratings are indicated as Research Octane Number (RON) and Motor Octane Number (MON). The difference between RON and MON is called the "sensitivity" of the fuel. Although the RON rating is the one indicated most commonly, it has increasingly been reported that the MON rating is more representative for the octane requirements of cars of recent years.

3.C. Octane Requirements of Automobiles

Of particular interest is the octane number requirement (ONR) of vehicles on the road. A direct method for obtaining octane requirement data from cars under normal service was developed by the Coordinating Research Council (CRC), for use by all participants in its periodic new-car Octane Requirements Surveys. This is referred to as the CRC E-15 method, and it measures maximum octane requirements in terms of both primary reference fuels (PRF) and full-boiling reference fuels (FBR and FBRU for leaded and unleaded fuels, respectively) that are typical of current commercial gasolines. The ONR is determined for full-throttle accelerations, as well as for the most critical part-throttle conditions.

Although the CRC E-15 method is representative of normal vehicle operation, this method nonetheless has some vague test conditions which may yield differences in the results. The following are examples of these unspecified conditions:

- a) Although the temperature and humidity of the atmosphere are known to have a major effect on the octane number requirement, the CRC E-15 method only requires that the "tests will be conducted on moderately dry days, preferably at ambient temperatures above 60°F, and should not be conducted during periods of high humidity such as prevail when rain is threatening or during or immediately after a rain storm."

b) The position of the rater is not defined completely. This can lead to differences in rating since the knock is judged by ear.

c) The procedure allows simulation of the road test on chassis dynamometers. Currently, less than half of the participant laboratories carry on the tests actually on the road. However, it is known that significant differences exist between the results from chassis dynamometer tests and actual road test. For example, E.S. Corner¹ has reported that for large samples of 1971 cars, in the region from 70 to 90% cars satisfied, the average RON for unleaded fuel was about two units higher for dynamometer tests than for actual road tests.

Time schedules and other constraints probably explain the looseness of some details of the CRC E-15 method. None the less, the method should be improved to eliminate as much uncertainty as possible, and means should be found for correcting the effect of those variables which cannot be maintained within proper limits.

The CRC octane number rating is determined on the basis of borderline knock as judged by trained raters. This is referred to as the "technical" rating. However, customer satisfaction occurs at lower octane numbers than those determined by the CRC procedure. Generally, the "customer" requirements are estimated to be two or three units lower than the "technical" requirements. This point is very significant and there is an urgent need to document and define what difference can actually be considered or tolerated between the "technical" and "customer" requirements.

The CRC is aware of the need for improving and complementing the CRC E-15 procedure. A CRC ad hoc committee has been formed to study what should be done regarding these matters.²

3.D. The Octane Requirement Increase (ORI)

As a new vehicle goes through its normal break-in process, deposits accumulate in the combustion chamber and eventually reach a stabilized level. The sources of these deposits are the fuel, the lubricant, and the air which enter the combustion chamber. The composition of the deposits depend on: a) the physical and chemical natures of the fuel and the lubricant, b) the additives in fuel and lubricant, c) the operating conditions of the engine, d) the weather and climate, and e) the location in the combustion chamber.

The deposits increase the octane requirements of the engines. The most significant reasons for this increase are the higher end-gas temperatures caused by the insulating effect of the deposits and the increase in compression ratio caused by the volume of the deposits.

The "octane requirement increase" is defined as:

ORI = (octane requirement of engine with stabilized deposits) -
(octane requirement of clean engine).

There is limited information on the ORI for automobiles operated with unleaded gasoline. However, the available data indicates that while cars operated with leaded fuel reach stabilized octane requirements before accumulating 5,000 miles, cars operated with unleaded fuel require more miles to reach stabilized requirements. Also, the ORI for cars operated with unleaded gasoline appears to be higher than the ORI for leaded-fuel cars. The CRC 1971 ORI Survey indicated, for 47 matched pairs of cars, that the average stabilized ORI was 3.8 RON for cars operated with leaded gasoline and 5.8 RON for cars operated with unleaded gasoline. The CRC 1973 ORI Survey determined, using unleaded full-boiling reference fuels, an average ORI of 8.4. 54% of the 1973 unleaded fuel cars had their ORI stabilized below 12,000 miles; the rest of the cars had stabilized octane requirements at a mileage of 12,000 miles or more.

The ORI is one of the most important items for determining whether there will or will not be a problem with the octane requirements of the 1975 model year cars. Therefore, to provide a well qualified answer to this question, ORI data for 1975 model cars is needed.

3.E. The Distribution of Octane Number Requirements

Because of the many factors which affect the octane number requirements, even identical cars may have large differences in octane number requirements. Typically, the distribution of octane number requirements of identical cars show, when operated with FBRU fuels, a variation of about 10 research octane units between the 5 and 95 percentiles. Naturally, the variability of the octane requirements for the whole car population of a given model year is even higher.

In automotive literature the percentiles of the distribution for octane number requirements are designated as "percent cars satisfied". Individual manufacturers vary in the conservatism of the design target which they use to assure that excessive customer complaints will not be received concerning knocking under operation with the specified fuel. It appears that traditionally, the design target--for cars with stabilized deposits--varied from 85 to 95% cars satisfied throughout

the automotive industry. Of course, when the unleaded fuel requirement was not a constraint, the unsatisfied cars could be satisfied, in general, by using other fuels normally available with higher lead content.

3.F. Effects of Light-Knock on Emissions, Performance, and Durability

The current concern for both fuel economy and engine knock makes it particularly appropriate to consider the potential benefits and dangers associated with light-knock operation. These matters are discussed in the following paragraphs.

The literature concerning the effect of knock on emissions is scarce. Some data is available, at steady state conditions, from two single cylinder engines and from four cars (one 1969 and three 1970 model cars) ^{3,4,5}. In general, comparing the results under light-knock and no-knock, these data indicate that:

- a) The variations of the CO and HC emissions were not significant.
- b) Light-knock operation increased the NO emissions.

It is difficult to quantify the increases in NOx emissions. The data from the four cars showed that the maximum increase was approximately 10% under heavy knock; therefore, with light-knock the percentage of NOx increase would be below 10%. Accordingly, the increases of NOx in these cars under the LA-4 driving cycle of the Federal test procedure should be small, since in this test knock would occur only during certain driving modes. To have accurate values of the increases of NOx in 1975 model cars which knock, it would be necessary to measure the NOx from some 1975 cars under operation with and without knock. For this purpose, the cars should be tested with unleaded gasoline of 91 RON/83 MON and with unleaded gasoline of higher octane number as required for operation without knock.

When an engine knocks slightly, retarding the spark will eliminate the knock. However, the spark retard will decrease the power output and the fuel economy. On the other hand, an increase in spark advance beyond a certain point will increase the knock and decrease the power output and fuel economy. Thus, the maximum output and fuel economy are obtained under some light-knock conditions.* This is because under knocking the gases in the combustion chamber vibrate, with heat losses as a result, but at some level of light-knock the gain from the faster combustion is greater than the heat loss caused by the vibrating gases.

* Supporting evidence for this statement is found in reference 6, page 298.

Whereas a certain level of light-knock is beneficial from the very important viewpoint of fuel economy, there are some questions about the feasibility of an extended use of light-knock operation. The first difficulty associated with permitting light-knock** operation is rating the level of knock. Currently, the only practical method of measuring knock is by ear; therefore, the intensity of knock may vary according to the particular observer. Rating the level of knock is much more difficult than simply distinguishing the following cases included in the CRC E-15 octane rating procedure:

- 1) no knock
- 2) borderline knock
- 3) above borderline knock.

Also, if some level of light knock is permitted within the normal ranges of speed, load, and weather, it must be considered that the knock will be higher under other conditions of operation which are more prone to induce knock. Furthermore, even if the knock would always be within a certain limit, there is a lack of information about the effect that this knock could have on engine durability and performance if it would occur for substantial periods of time. There are differences in opinion of whether the effects of such a substantial occurrence would be serious or not.

Therefore, it appears that to allow for the general use of light-knock operation with confidence that it will not cause serious hardship, two precautions should be taken. First, it would be necessary to establish a procedure to properly measure the level of light-knock. Second, it would be required to determine what level of light-knock would be permissible without penalizing performance or durability. However, the determination of a feasible level of light-knock is further complicated by the fact that different engines may be able to tolerate different levels of knock.

Supposedly, if light-knock was permitted for 1975 cars or future model years cars, it would be the responsibility of the automotive manufacturers to verify that such knock would not impair the durability or the performance of the engines. As was indicated before, the CRC has set up an ad hoc committee that will study what sort of program should be started to define the relationship between "technical" and "customer" octane number requirements.² However, it is doubtful if this CRC committee will address the issue of the effects of light-knock on durability and performance.

** The expression "light-knock" is used in this report to indicate the region of knock intensity immediately above the borderline of knock. Some literature uses expressions such as "audible knock" to refer to the first portion of the knock region beyond "trace" or "borderline knock".

4. Octane Number Requirements for a Sample of 138 1975 Model Year Cars

The National Petroleum Refiners Association (NPRA) and, separately, the Mobil Research and Development Corporation, expressed their concern about the octane number requirements of the 1975 cars. They submitted to the EPA (on December 13, 1974, and January 6, 1975, respectively) data on the RON requirements for a sample of 138 cars. This data was obtained through the Coordinating Research Council Informal Data Exchange Program, on clean engines, following the CRC E-15 octane rating method, and using 1974 CRC FBRU or CSU-8* unleaded reference fuels.

This CRC data is the largest sample of data that has been made available to the EPA in octane requirements for 1975 model year cars. An analysis of this data is summarized in the following section 4.A. Some details on the data gathered and submitted by the participant laboratories are presented in Section 4.B.

4.A. Summary of the Analysis of the Data

For this specific data, on the basis of: **

- a) weighting the data according to the new car production figures projected for the 1975 model year,
- b) assuming that the "customer" RON requirements are two and a half units lower than the "technical" RON requirements, and
- c) decreasing the RON requirements by one unit, to compensate for the fact that actual road knock ratings are somewhat lower than chassis dynamometer ratings,

the TAEB of the EPA has estimated that the percentages of cars satisfied with the 91 RON/83 MON unleaded gasoline would be as follows:

For ORI = 4, approximately 78% cars satisfied
 For ORI = 6, approximately 62% cars satisfied
 For ORI = 8, approximately 44% cars satisfied. ***

* 1974 FBRU designates full-boiling range unleaded reference fuels which approximate the characteristics of commercially available unleaded gasoline in 1974. The sensitivity (that is, RON minus MON) of the FBRU fuels increases progressively with the RON, ranging from about 6 at 84 to 10 at 100 with a value of about 8 for 91 RON. CSU-8 designates full-boiling range unleaded reference fuels which maintain about 8 sensitivity throughout the range. These CSU-8 fuels were used by some laboratories in some low octane requirement cars.

** Details of the analysis can be found in reference 7.

*** However, the analysis of the CRC interim results obtained more recently indicates that the percentage of cars satisfied will be higher, see note in page 1-1.

It must be pointed out that the 1975 model year car population may have RON requirements different from those indicated by the CRC sample of 138 cars. According to the production data submitted to the EPA for certifying the 1975 model year cars, this CRC sample included models which represented only about five and a half million out of the total ten million cars that were projected for the 1975 model year domestic car population.

If: 1) the difference between "technical" and "customer" octane requirements is taken as two units, 2) the difference between chassis dynamometer and actual road ratings is neglected, and 3) a value of 8 units is considered for the ORI, then the percentage of cars satisfied with the 91 RON/83 MON unleaded gasoline would only be about 30%. This is approximately the percentage of cars that would be satisfied according to the estimate indicated by the Mobil Research and Development Corporation in its letter of January 6, 1975.

The National Petroleum Refiners Association was less specific in its estimate of the percentage of cars satisfied. In its letter of December 13, 1974, it indicated that "over one-half of the 1975 model vehicles can be expected to experience knock on 91 RON gasoline".

Analysis from others consider that the ORI for unleaded gasoline will be not too different from the ORI for leaded gasoline and estimate that higher percentages of cars will be satisfied. The Exxon Research and Engineering Company, for instance, indicated, on January 29, 1975, at the public hearings on the application for suspension of the 1977 LDV emission standards, that the unleaded gasoline on the market will satisfy something on the order of 88 percent of the 1975 vehicles.

To summarize, the accuracy of the prediction of the percentage of cars that will be satisfied with 91 RON/83 MON unleaded gasoline depends basically on: 1) what difference can actually be considered or tolerated between "technical" and "customer" RON requirements, 2) what is the actual ORI in customer use for stabilized engines, and 3) how representative of the new 1975 car population is the sample of cars used for determining the RON requirements. Therefore, to refine the prediction, more conclusive information on these three items is needed.

4.B. Summary of the Data Submitted by the Participating Laboratories

In responding to the NPRA's letter of December 13, 1975, Mr. Stork, DAA for the MSAPC of the EPA, requested that the companies which had contributed in obtaining information on the ONR provide their data, in detail, directly to the EPA. A summary of the data that has been received by the EPA in response to this request follows.

Amoco Oil Company

In a letter dated January 16, 1975, Amoco indicated that they had tested thirty-nine 1975 model cars. These cars had less than 1,000 miles on the road when tested. In this group of 39 cars, the "technical" RON requirements--using 1974 FBRU fuels--were:

- 1 car (i.e., 3%) required 89.5 RON
- 5 cars (i.e., 13%) required \geq 87 RON
- 7 cars (i.e., 18%) required \geq 85 RON
- 32 cars (i.e., 82%) required $<$ 85 RON.

For 11 of the cars, data was also obtained when they reached 4,000 miles. The ORI ranged from 0 to 7 units and averaged 2.8. The maximum requirement was 95 RON.

Ethyl Corporation

In a letter dated January 14, 1975, the Ethyl Corporation informed the EPA that they had contributed data from nine 1975 vehicles. These cars were tested, in their "controlled weather" chassis dynamometer rooms, when they had less than 1,000 miles. For these nine cars, the "technical" RON requirements--using 1974 CSU-8 fuels--were:

- 1 car (i.e., 11%) required 91 RON
- 2 cars (i.e., 22%) required \geq 89 RON
- 7 cars (i.e., 78%) required $<$ 89 RON.

Gulf Research and Development Co.

On November 15, 1974, Gulf sent data from seven 1975 cars. The data was taken in its "all weather" chassis dynamometer. With less than 1,000 miles, using 1974 FBRU fuels, the "technical" RON requirements of these seven cars were:

- 2 cars (i.e., 29%) required 87 RON
- 5 cars (i.e., 71%) required $<$ 87 RON.

Sun Oil Company

On January 29, 1975, Sunoco sent to the EPA the data from fifteen 1975 model cars. Only four of these cars had been included in the NPRA list of 138 cars, since the other eleven cars were tested at a later time. The cars were tested at less than 1,000 miles, on the chassis dynamometer. Using 1974 FBRU fuels, the "technical" RON requirements of these fifteen cars were:

- 1 car (i.e., 7%) required 92 RON
- 2 cars (i.e., 13%) required \geq 90 RON
- 5 cars (i.e., 33%) required \geq 89 RON
- 10 cars (i.e., 67%) required $<$ 89 RON.

Cities Service Oil Company

Cities Service sent to the EPA, on February 18, 1975, ONR data from eight 1975 cars. This data had been obtained using 1973 FBRU fuels and had not been included in the NPRA data from 138 cars. The data from these eight cars had been taken at substantially different mileages. The highest "technical" octane requirements were 91 and 90 RON for two vehicles with 5,666 and 11,120 miles, respectively. The other six cars had lower mileages, and their requirements were equal or less than 85 RON.

Ashland Oil, Inc.

Ashland sent to the EPA, on January 13, 1975, ONR data from 29 low mileage 1975 model year cars. This information was taken using PRF instead of FBRU fuels, and was not obtained by the CRC E-15 method, but with the Modified Uniontown technique. It was not included in the data submitted by the NPRA. No meaningful conclusions can be extrapolated from these data regarding satisfaction when using FBRU fuels and the CRC E-15 method.

Phillips Petroleum Company

Phillips submitted, on March 5, 1975, to the participants of the CRC 1975 Informal ONR Survey, data from fifteen 1975 cars. This data is not included in the data from the 138 car sample since it was obtained later, in January and February of 1975. This data is from low mileage cars (ranging from 89 to 3,505 miles) and was taken using a chassis dynamometer, at 75°F and low relative humidity. Using CRC 1974 CSU-8 fuels, the "technical" RON requirements were:

1 car (i.e., 7%) required 90.5 RON
 4 cars (i.e., 27%) required \geq 89 RON
 11 cars (i.e., 73%) required $<$ 89 RON.

E. I. DuPont de Nemours & Co.

DuPont submitted to the EPA, on January 22, 1975, data from fifty 1975 cars. This data was from low mileage cars (below 400 miles) and was taken using a chassis dynamometer. The data was obtained using a DuPont prepared series of full-boiling range unleaded reference fuels instead of the CRC 1974 FBRU fuels. This data was not included in the NPRA data from 138 cars. From its data, DuPont has estimated the "technical" RON requirements of these 50 cars for the CRC 1974 FBRU fuels; in summary, these requirements would be:

1 car (i.e., 2%) would require 97.4 RON
 2 cars (i.e., 4%) would require \geq 95 RON
 9 cars (i.e., 18%) would require \geq 90 RON
 20 cars (i.e., 40%) would require \geq 88 RON
 30 cars (i.e., 60%) would require $<$ 88 RON.

5. Effects of Spark Retard

To decrease or eliminate engine knock when there is not the possibility of using a higher octane gasoline, the simplest solution is to retard the spark timing. Thus, spark knock can be decreased or eliminated by spark retard; but this action also has other effects which are considered in the following sections.

5.A. Effect of Spark Retard on Gasoline Consumption

The fuel economy of automobiles depends very significantly on the timing of the ignition. Therefore, even though spark retard reduces octane number requirements, it also reduces fuel economy. It is shown in Figures I-1 through I-3 that while one degree of spark retard will reduce the octane requirements about one number, more than 4-5 degrees of retard will cause the fuel economy to degrade drastically. Therefore, spark retard is considered a reasonable approach to octane requirement reduction only within the range of 1° to 5°, where one degree of spark retard causes only about 1% deterioration in fuel economy.

EPA technical staff have estimated* the nationwide fuel economy losses that would result if the spark were retarded up to a maximum of 4° to satisfy a greater fraction of the 1975 model year cars with 91 RON/83 MON unleaded gasoline. Using the clean engine RON requirements of the 138 1975 model year cars tested under the CRC Informal Data Exchange Program, and on the basis of:

- a) weighting the data according to the new car production figures projected for the 1975 model year,
- b) assuming that the "customer" RON requirements are two and a half units lower than the "technical" RON requirements,
- c) decreasing the RON requirements by one unit to compensate for the fact that actual road knock ratings are somewhat lower than chassis dynamometer ratings,
- d) estimating that fuel economy (mpg) deteriorates 1% per unit of octane number gained (by spark retard), up to 5 RON units of gain**, and

* Details on the analysis can be found in reference 8.

** The EPA does not have much data available on the percentage of fuel economy lost per unit of octane number gained by spark retard. The values used in the analysis are the averages from a few available data, and are consistent with the values quoted by the auto industry. For accuracy, more data is needed. Furthermore, the actual percentage of the decrease in the mpg will also vary upon whether the spark retard is achieved by simply changing the distributor timing--which will provide a constant spark retard--, or by the more sophisticated method of modifying the ignition timing mechanisms for load and speed as required for minimum fuel economy losses.

e) assuming that, as a first approximation, the aggregate consumption of gasoline is proportional to the number of cars, i.e., approximately independent of the type of cars,

the estimated increase in gasoline fuel consumption for the 1975 car population is:

For ORI = 4, approximately 0.5%
 For ORI = 6, approximately 0.8%
 For ORI = 8, approximately 1.6%.

Actually, the corresponding percentage of increase in gasoline fuel consumption would be somewhat less because: 1) not all the 1975 model year cars use catalysts, and 2) some cars will use available unleaded gasoline of higher than 91 RON.

It can be assumed that the 1975 model cars will constitute approximately 10% of the overall car population. Therefore, these fuel consumption increases of 0.5%, 0.8%, or 1.6% (for ORI = 4, 6, or 8, respectively) for the 1975 model year car population would mean increases of 0.05%, 0.08%, or 0.16%, respectively, in the total gasoline consumption of the overall car population in the USA.

If this case (i.e., if the ignition timing were retarded as needed, up to a maximum of 4°), it is estimated that the percentages of cars satisfied with 91 RON/83 MON unleaded gasoline would be:

For ORI = 4, approximately 95% cars satisfied
 For ORI = 6, approximately 89% cars satisfied
 For ORI = 8, approximately 78% cars satisfied.

5.B. Effect of Spark Retard on Exhaust Emissions

It is well known that spark retard decreases the emissions of NO_x. Therefore, in this regard, the retarding of the ignition timing is beneficial (see Figure I-4).

Also, in general, the exhaust emissions of HC decrease with spark retard. The limited data obtained with the spark timing retarded (specifically to decrease the octane requirements) show that this is the general trend (See Figure I-5). In some cases the data indicated increases of HC, but even in these instances the absolute values of HC were several times lower than the 1975 standards for HC.

The concentration of CO at the outlet of the cylinders of the spark ignition engine is known to depend almost exclusively on the air-fuel ratio of the mixture fed to the cylinders. Accordingly, unless the higher exhaust temperatures associated with spark retard result in a higher oxidation of CO, some increase in the mass emissions of CO could be expected. This increase would occur because of the larger exhaust flow caused by the increased fuel consumption associated with spark retard. However, the increases in mass emission of CO appear to be much larger than what could be expected on the basis of fuel economy deterioration. The limited data which is available (Figure I-6) shows variations of CO mass emissions ranging approximately from -15% to +300%. Possibly, the high increases in CO emissions can be explained by the increased operation under enriched carburetion, which might result from the increased throttle opening associated with retarding the ignition timing. Nevertheless, if no more than 4°-5° of spark retard are permitted, to minimize impact on fuel economy, the absolute increases in CO emissions do not appear large. Therefore, if this data on CO emissions is representative of the general situation, it appears that spark retard would not impede fulfillment of the 1975 emission regulations.

5.C. Effects of Large Spark Retards

Normally, a few degrees of spark retard would have no noticeable adverse effects other than those on fuel economy and on some emissions, as indicated before. However, large retardations in the spark timing will not only result in large fuel economy losses and increased emissions of some pollutants, but will also cause a loss in power and driveability of the vehicle. In addition, since spark retard increases the exhaust gas temperature, large retardations in the spark timing can result in such problems as engine overheating, burned valves, shortened spark plug life, and preignition.

6. Specific Documentation

A few comments concerning some of the more significant documents which were reviewed for preparing this report are presented in this section.

"Summary of Responses to EPA Request for Information on ORI for 1975 Model Automobiles"

This document is dated September 11, 1974. Briefly, it shows that the four major U.S. auto manufacturers did not expect serious difficulties with the ON requirements of the 1975 cars. Also, the manufacturers indicated that any problems in the field will be easily corrected by spark retard.

Public Hearings on the Application for Suspension of the 1977 LDV Emission Standards

The records of these hearings, which were held on January of 1975, indicate that each of the U.S. auto manufacturers testified that they had not received unusual complaints concerning knocking with 1975 model cars.

These records were consistent with the findings of a small survey made in January of 1975 by the TAEB of the EPA. Car dealers of all the major U.S. auto manufacturers were contacted by telephone in the Ann Arbor (Michigan) area, and none indicated that they had received any complaints about knocking.

It must be noted, however, that these records do not guarantee that there will not be complaints in the future, if the hot weather and the accumulation of mileage expose audible knock.

SAE Panel Discussion on Octane Number Requirements of 1975 Model Year Cars

The SAE panel discussion on ONR of the 1975 cars (held in Detroit, on February 27, 1975) provided an account of the views on the subject.

In general, the U.S. auto manufacturers restated that there will be no serious problems, and that the unsatisfied cars will be taken care of with a few degrees of spark retard.

On the other hand, the participating petroleum and fuel additive companies indicated that unusually high numbers of 1975 cars will not be satisfied with the 91 RON/83 MON unleaded gasoline. Their estimates of 1975 satisfied cars ranged from 30 to 80%, approximately.

Panelists of both automotive and fuel companies pointed out the need to improve the procedure for determining the "customer" octane number requirements of automobiles.

In addition, Chrysler and Ford spokesmen suggested that greater attention should be paid to increasing the availability of higher octane unleaded gasolines. Specifically, Ford's spokesman indicated that unleaded gasolines of 95 or 96 RON should be made generally available in the future to maximize the energy availability from petroleum.

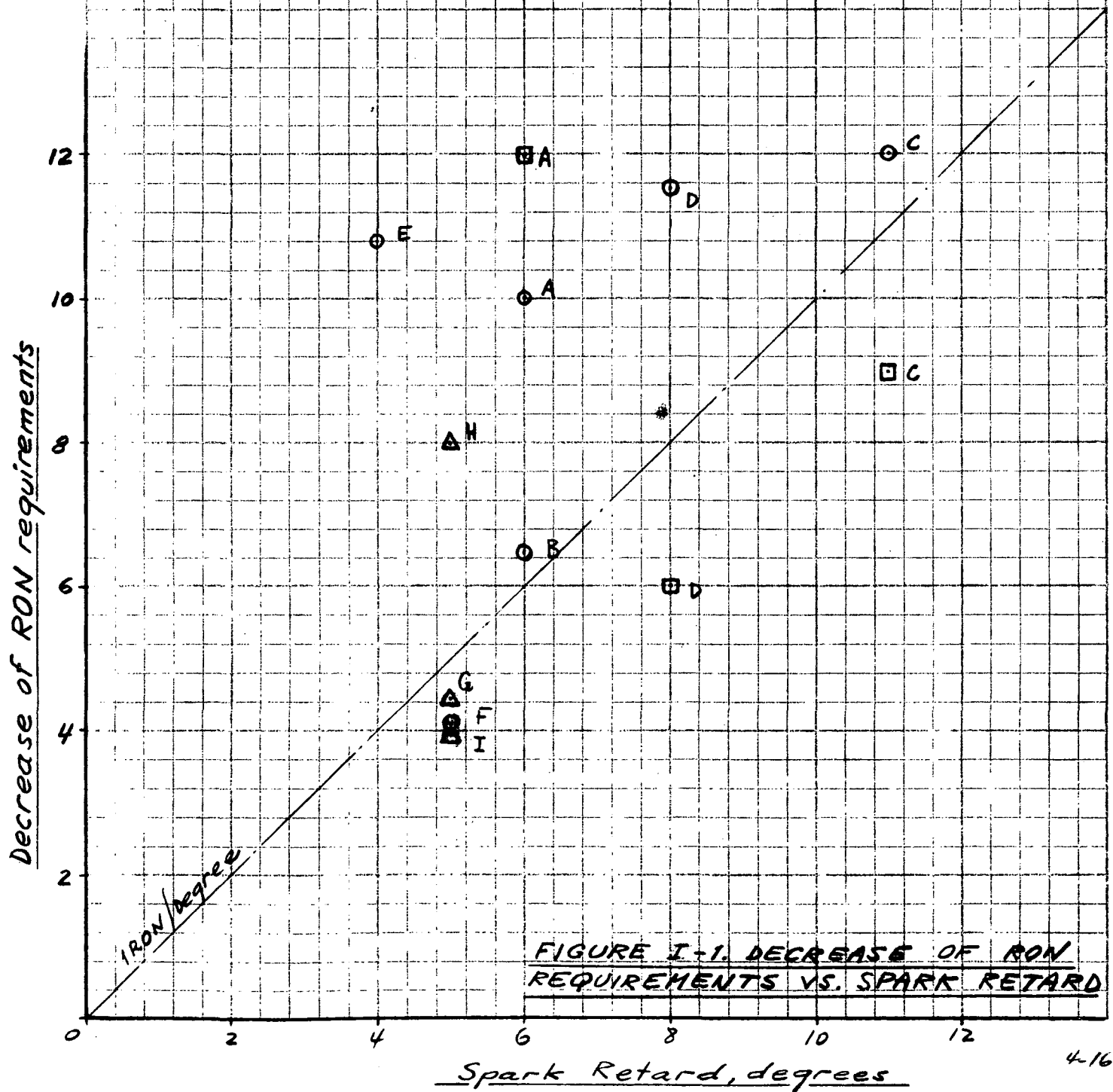
8. References

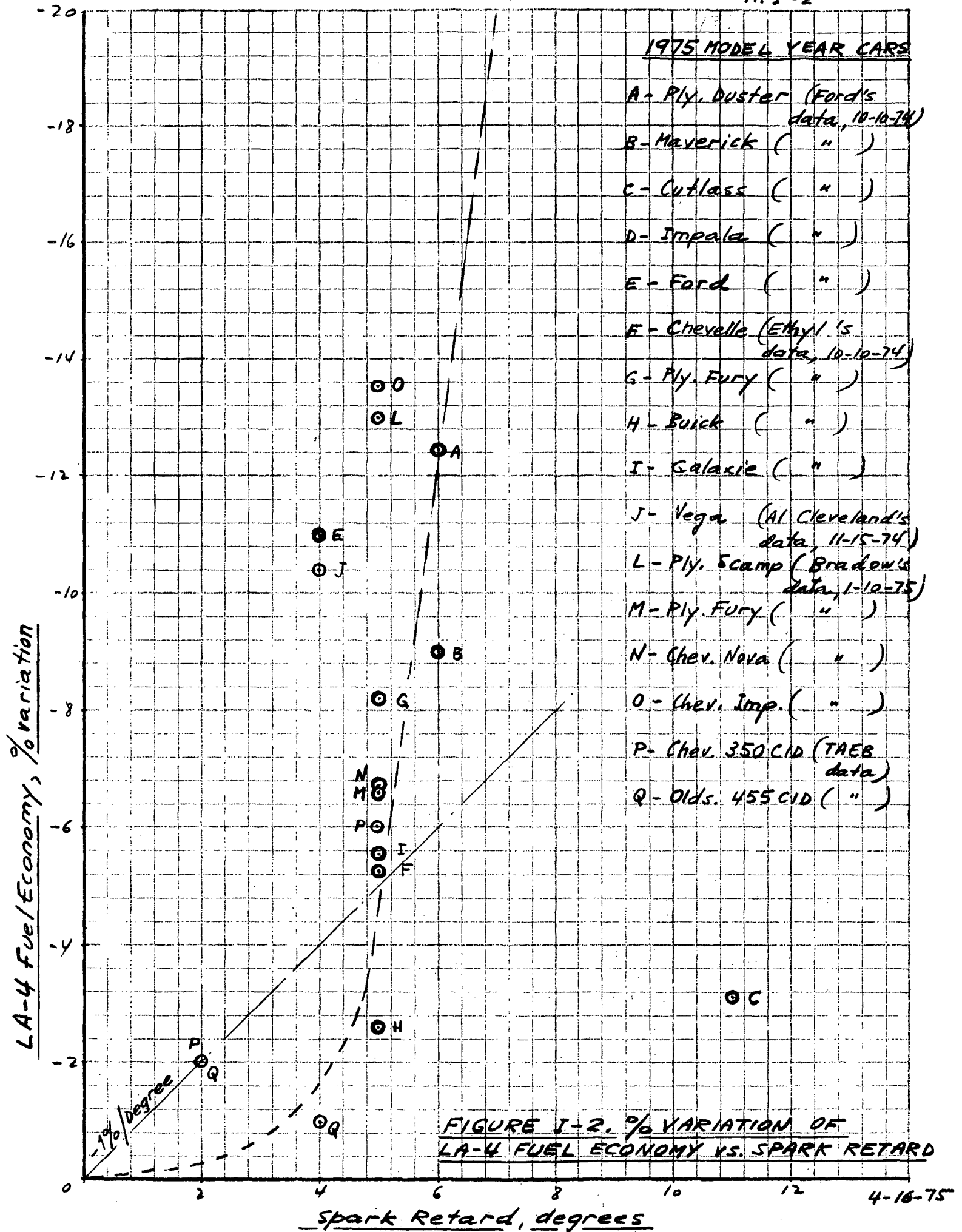
1. "Octanes on the Road-Leaded and Unleaded", E. S. Corner, API pre-print No. 02-72, May 9, 1972.
2. "February Meetings of the CRC Groups Related to Octane Number Requirements", memo by J. L. Bascunana, EPA, March 6, 1975.
3. "The Relation Between Knock and Exhaust Emissions of a Spark Ignition Engine", L. C. Duke et al., SAE paper No. 700062.
4. "The Effects of Knock on the HC Emissions of a Spark-Ignition Engine", H. P. Davis et al., SAE paper No. 690085.
5. "Effect of Knock on Exhaust Emissions", W. Brown, September 10, 1970, MPR 8-70 memo from Ethyl Corporation.
6. "Internal Combustion Engines", E. F. Obert, International Textbook Company, 3rd edition, 1968.
7. "Analysis of the RON Requirement Data from 138 Cars of the 1975 Model Year", memo by J. L. Bascunana, EPA, February 11, 1975.
8. "Estimated Fuel Economy Losses for Elimination of Knocking in 1975 Model Cars by Spark Retard", memo by J. L. Bascunana, EPA, January 21, 1975, updated on April 2, 1975.

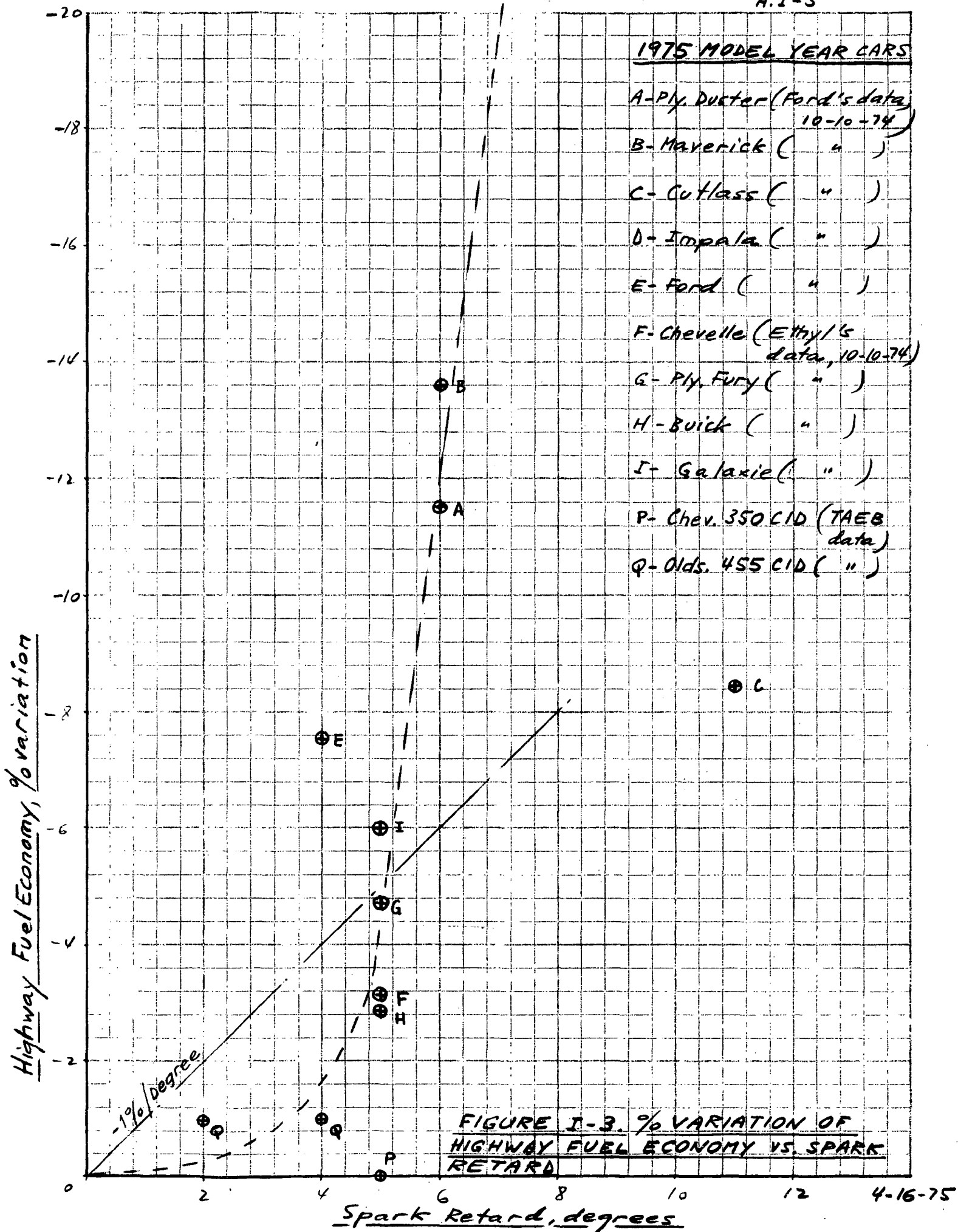
1975 MODEL YEAR CARS

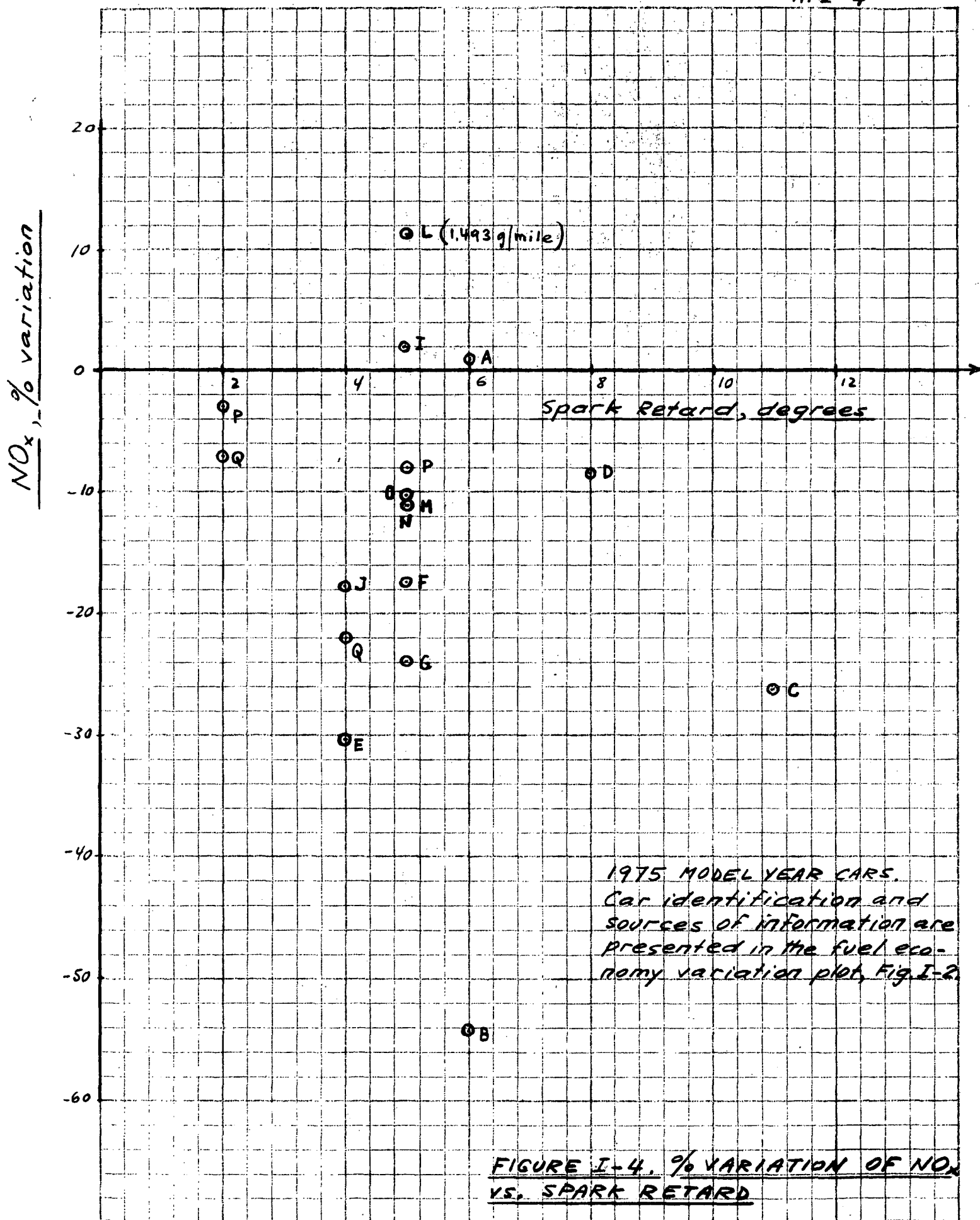
The identification of the cars and the sources of information are presented in Figure I-2.

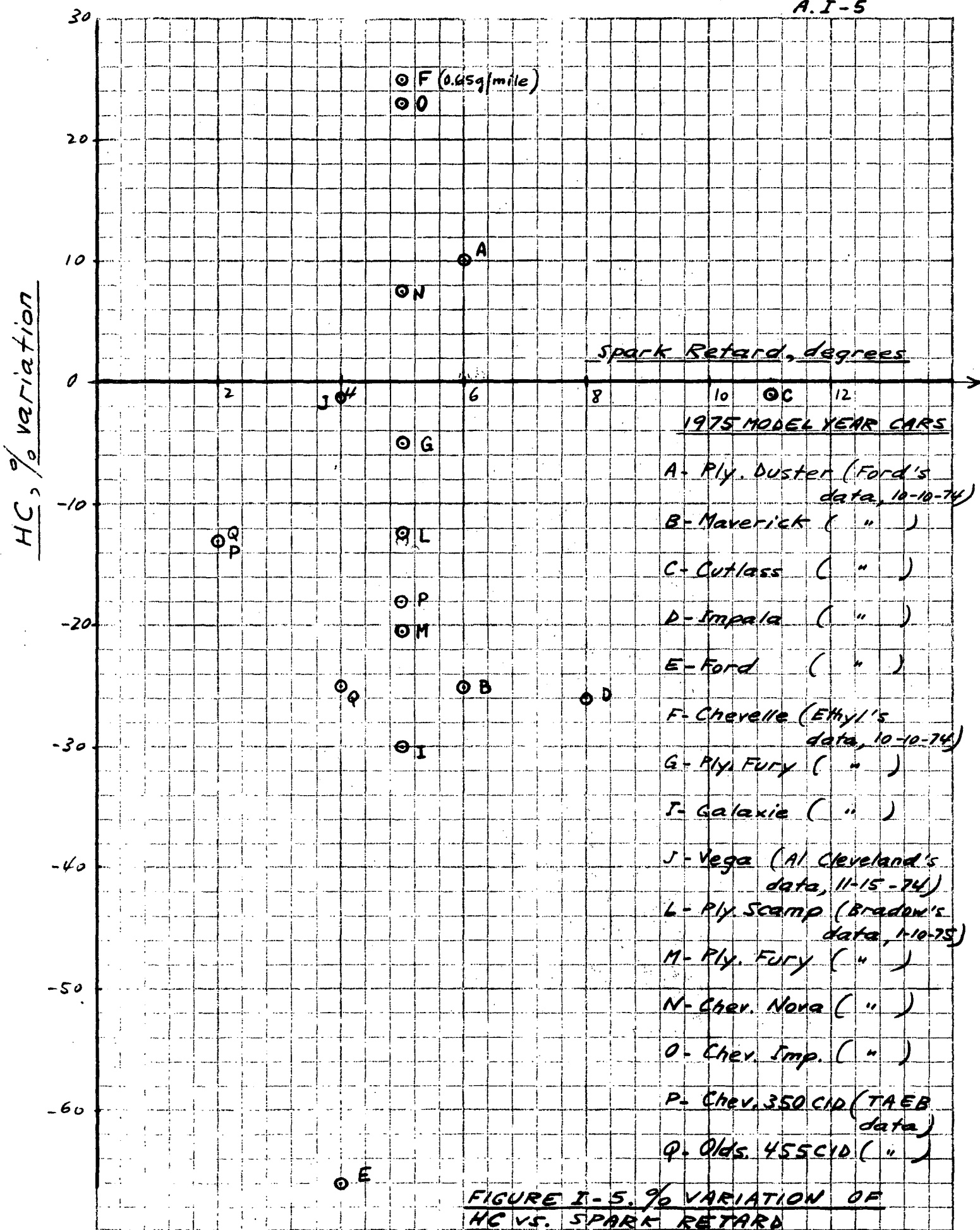
- WOT conditions
- PT conditions
- △ Unknown conditions











319% ↑ ○ A (8.21 g/mile)

A. I-6

