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SOME SOURCES OF ERROR IN LABORATORY KNOCK RATINGS

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By W. E. ADAMS* and J. D. McCULLOUGH†

It is the intent of this paper to make *quantitative* comparisons of the relative importance of several factors known to affect Research octane ratings.

Knowing which factors are of *greatest* importance may provide direction for industry-wide cooperative investigations of these factors and eventual improvement in octane ratings.

Furthermore, knowledge of the magnitudes of the effects of individual parameters (on octane ratings) could assist individual laboratories in estimating the degree of control of each variable which is required to meet their objectives.

HISTORICAL NEED FOR IMPROVEMENT

Through standardization of equipment and procedures, and much operating experience, octane ratings have been made sufficiently reproducible to meet the needs of the refining industry in the past.

It is inherent in the nature of a virile industry, however, to be dissatisfied with today's performance and to constantly strive for improvement. Current dissatisfaction with octane ratings centers about the reproducibility of the Research method above the 98-octane level and of the Motor method above the 95-octane level.

Figure 1 summarizes the experience of the ASTM National Exchange Group through the year 1958.[1] Laboratories participating in the National Exchange Group (NEG) rated identical samples of fuels spanning a broad range of hydrocarbon types and octane levels. Using the standard deviation of the reported ratings as a measure of the diversity of data, Figure 1 shows that the Research method is fairly reproducible when rating fuels in the 90- to 98-octane range. However, when rating fuels near 105 Research octane number (RON), less confidence can be placed in the rating. In general, the Motor method is never as reproducible as the Research method and merits even less confidence above 95 octane number. Since 1958, increased familiarity with fuels above 100 octane number has, undoubtedly, improved this picture to some extent.

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CAN THE VARIABLES BE SEPARATED?

Figure 1 showed that the reproducibility of knock ratings is a function of the octane level at which the rating was made. It seems imperative that the industry know whether this trend is characteristic of the Research and Motor methods, or whether it represents differences in equipment and technique among individual laboratories.

It is certainly impractical to investigate all of the possible combinations of circumstances in many laboratories which could cause lack of agreement of octane ratings. However, it does seem possible to separately study the effects of those factors likely to differ among laboratories if the study is made under carefully controlled conditions.

Therefore, the authors determined to measure the effect, on a selected test fuel, of small changes in each separate factor, while holding all other conditions constant. The relative importance of each factor could then be assessed by comparing the resultant changes in the octane rating of the selected fuel as each factor was varied.

Before such a comparison could be made, it was felt necessary to determine the precision with which the effects of each factor could be measured. This was established by determining the ultimate capability of the Research method to repeat itself.

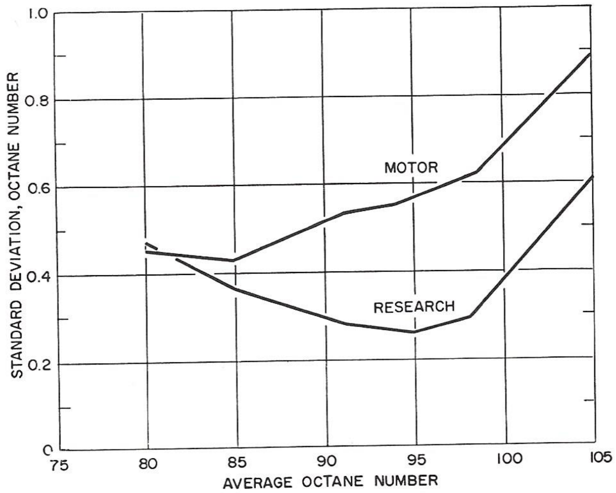

Figure 1. Reproducibility of Ratings.

ASTM National Exchange Group—1947 through 1958.

ESTABLISHING A BENCH MARK FOR THE RESEARCH METHOD

Experiments were performed using the split-head cylinder mounted on a CFR-48 crankcase. The engine was equipped with standard accessories. All tests were performed using the ASTM Research method while holding conditions as closely as possible to those recommended.

The cylinder-height micrometer setting (compression ratio) used for the ratings below 100 RON were those listed in ASTM D 908 (Research method). For ratings above 100 RON, the "intermediate" guide curve[2] was used. The ASTM corrections of compression ratio and intake air temperature were applied for changes in barometric pressure.

A strip-chart electric recorder was substituted for the knockmeter. This insured that readings were taken under stable conditions. It also minimized operator bias when recording knockmeter readings, since octane numbers of the ratings were calculated from the record after all the ratings were completed. These techniques required much more time per rating than would normally be tolerated. However, the very nature of the experiments placed a strong emphasis on accuracy of data, with little thought for the time required.

Two separate determinations of the "repeatability" of the Research method were made.

The first tests used an unleaded paraffinic reference fuel (nominal 99.5 RON) to minimize any possible effects resulting from deposits or hydrocarbon type differences. All engine parameters were held constant while 25 consecutive ratings of the "unknown" were obtained.

The data tabulated in Table 1 show that the standard deviation of the octane number determinations was 0.016 RON.

A more realistic appraisal of the routine capabilities of the Research method was obtained by repeatedly rating a commercial-type fuel at the 103-RON level. This fuel was especially blended to be representative of those hydrocarbon types which are difficult to rate. Tetraethyllead was added to reach the 103-RON level. The specifications for this fuel, hereinafter called Fuel A, are listed in Table 2. Knock-test operators reported this fuel "a tough one to rate."

After the engine was operated to deposit stability on leaded fuels, 20 strip-chart records were obtained on Fuel A. The results are reported in Table 3. The standard deviation was 0.04 RON.

Such results tend to substantiate the opinion that the reproducibility of ratings is related to the octane number, the hydrocarbon type of the fuel sample, or both.

TABLE 1

Repeatability of Research Method for Unleaded Paraffinic Fuel

Rating Number	Observed Rating (Research Method)
1	99.52
2	99.48
3	99.50
4	99.49
5	99.52
6	99.50
7	99.51
8	99.51
9	99.52
10	99.51
11	99.49
12	99.51
13	99.51
14	99.51
15	99.50
16	99.51
17	99.50
18	99.50
19	99.49
20	99.49
21	99.48
22	99.48
23	99.48
24	99.49
25	99.45

Average rating = 99.50 RON.
Standard deviation = 0.016 RON.

The standard deviations for repeated ratings are, quite naturally, considerably smaller than the reproducibility of the laboratories shown in the NEG data (Figure 1). Because the difference is so marked, it seems apparent that nationwide reproducibility is determined by differences in equipment and techniques rather than inherent inadequacies of the method.

TABLE 2

Inspection Data for Fuel A

Nominal Octane Ratings	
Research	103.4
Motor	91.5
Hydrocarbon Type, vol %	
Aromatics	47
Olefins	21
Saturates	32
Tetraethyllead, ml/gal.	2.03
Gravity, ° API	49.0
ASTM Distillation, °F	
10 per cent evaporated	157
50 per cent evaporated	281
90 per cent evaporated	331

TABLE 3

Repeatability of Research Method for Fuel A

Rating Number	Observed Rating (Research method)
1	103.16
2	103.17
3	103.21
4	103.23
5	103.20
6	103.20
7	103.18
8	103.19
9	103.21
10	103.25
11	103.31
12	103.27
13	103.25
14	103.27
15	103.26
16	103.22
17	103.23
18	103.25
19	103.22
20	103.17

Average rating=103.23 RON.
Standard deviation=0.04 RON.

EVALUATING THE DIFFERENT FACTORS

The Effects of Tolerances of the Research Method

The Research method, as defined by the American Society for Testing Materials, has tolerances specified for some of the operating variables. These tolerances allow certain limits within which a given variable may be set. It is possible that the cumulative effects of these tolerances can account for the variation in ratings throughout the refining industry. Therefore, it was believed desirable to know the individual effects of each tolerance permitted.

To define the effects of permitted tolerances, all other variables were held as constant as possible, and the particular variable under study was varied in discrete steps through a broad range.

The individual influence of each variable is reported in the following sections.

Engine Speed

The Research method specifies that engine speed shall be 600 ± 6 rpm. Figure 2 illustrates the effect of small differences in engine speed on the rating of Fuel A. Three discrete speeds were available on the test engine: 614, 622, and 637 rpm. The linear relationship of the data for these speeds justified extrapolation of the line to below 600 rpm. The vertical dotted lines indicate the limits permitted by the method. Figure 2 shows that the rating of Fuel A might be changed as much as 0.12 RON as a result of permissible differences in engine speed alone.

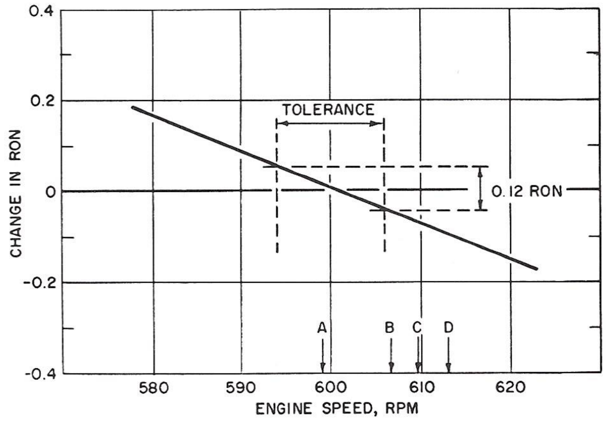

Figure 2. Effect of Engine Speed on Fuel A.

The short arrows, labeled A, B, C, and D, on the abscissa of Figure 2 indicate speeds measured in a spot check of four typical engine installations. Engines A and D would have differed in rating Fuel A by 0.14 RON.

Intake Air Temperature

A tolerance of ± 2°F is permitted, at the specified intake air temperature, by the Research method. Figure 3 shows that the rating of Fuel A changes by 0.10 RON throughout the 4°F range permitted.

The specifications for the ASTM fuel-rating air thermometer, 83F-55T, permit an additional ± 2°F tolerance for the thermometer scale error. In effect, this factor opens the actual test tolerance for intake air temperature to ± 4°F. In the event that both the test tolerance and the thermometer tolerance were in the same direction, two different laboratories might disagree by 0.2 RON when rating Fuel A.

Cylinder Height

Ratings are considered acceptable by the Research method if the compression ratio has been adjusted to within ±0.025 in. of the cylinder height recommended by the guide curve for the octane number of the test fuel.

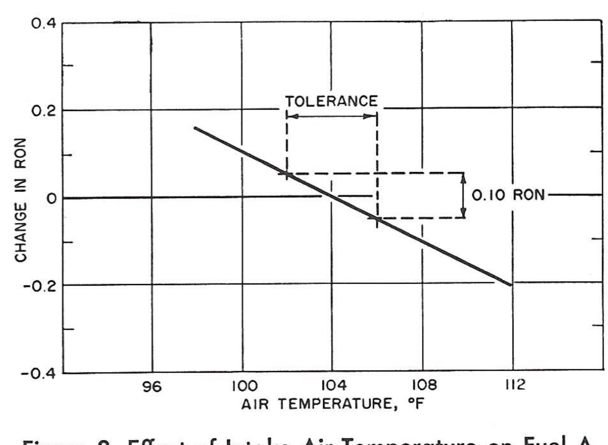

Figure 3. Effect of Intake Air Temperature on Fuel A.

Figure 4 shows that engines operating at the extremes of this tolerance would differ in rating Fuel A by 0.16 RON.

This same information may be interpreted in terms of the effect of errors in setting the initial clearance volume when mounting the cylinder-height indicator to the engine. The Research method permits a tolerance of ±0.5 ml in setting the combustion chamber clearance volume (equivalent to ±0.0037 in. of cylinder height). If the actual clearance volume has been set within these limits, differences in cylinder height could account for only 0.03-RON change in the rating of Fuel A.

Effect of Changes in Barometric Pressure

ASTM tables are provided to permit engine compression ratio and intake temperature to be adjusted in such a manner as to minimize the effects of changes in barometric pressure on ratings.

The tables provided were empirically derived from the results of many experiments on primary reference fuels and commercial fuel types. Industry committees have recognized that the corrections for barometric differences are not appropriate for many fuels. The effect of barometric pressure was investigated by throttling the inlet to a series of large surge chambers which were connected to the intake air heater. Each test pressure was held constant within 0.02 in. of mercury.

The suitability of the recommended corrections for barometric changes when rating Fuel A is shown in Figure 5. In this case, a laboratory at sea level and a laboratory at an elevation of nearly 4,000 ft. would differ by as much as 0.6 RON when rating Fuel A.

Effect of Engine Variables Specified Without Tolerances

Some of the engine variables which are specified in the Research method have no recommended tolerance limits. In these cases, an experience factor has been used to estimate the probable limits of variability to be found in practice.

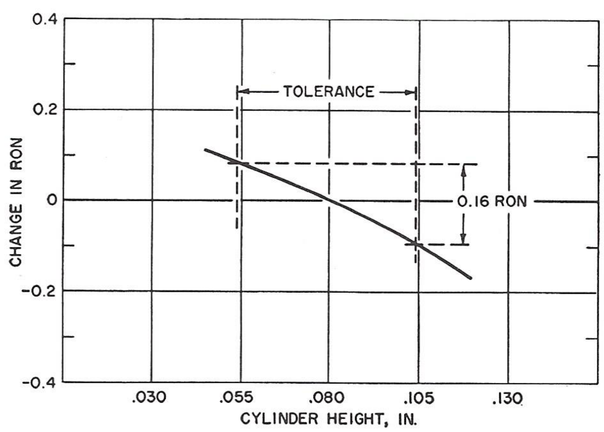

Figure 4. Effect of Cylinder Height on Fuel A.

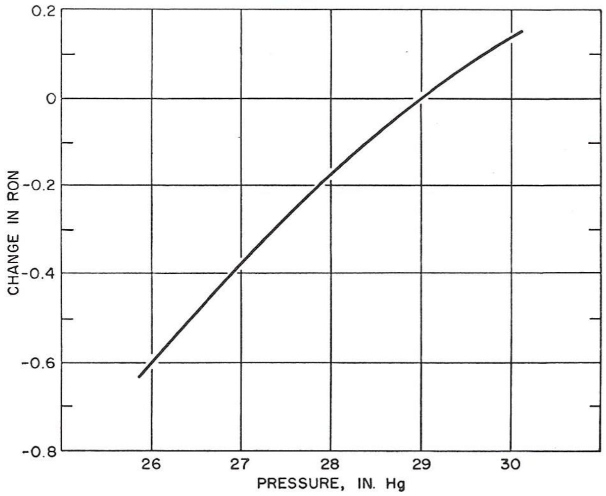

Figure 5. Effect of Barometric Pressure on Fuel A.

Fuel-Air Ratio

No instrumentation is provided to measure fuel-air ratio in the Research method. However, a sight glass is provided to indicate the level of the fuel in the fuel bowl. A relative scale of 0 in. to 2 in., calibrated in 0.1-in. increments, is engraved on the sight glass. The test specifies that the fuel height shall be adjusted to give maximum knock.

Figure 6 indicates that the standard carburetor design requires that the fuel level be set and held within 0.050 in. of the maximum knock value to rate Fuel A within 0.1 RON.

The implication is quite strong that the effective fuel level must be maintained within close limits if a given rating is to be significant. However, in practice, bubbles forming in the fuel passages cause variations in the effective fuel height. Such variations are reflected in variations in knock intensity, with attendant "wandering" of the knockmeter pointer. When such pointer motion is apparent, the operator must exercise his

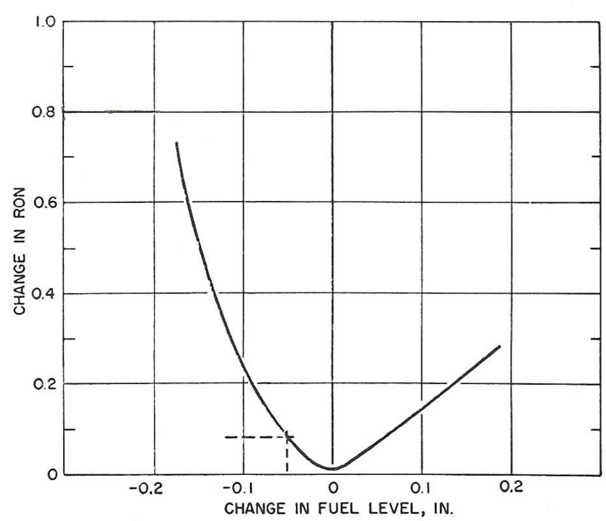

Figure 6. Effect of Fuel-Air Ratio on Fuel A.

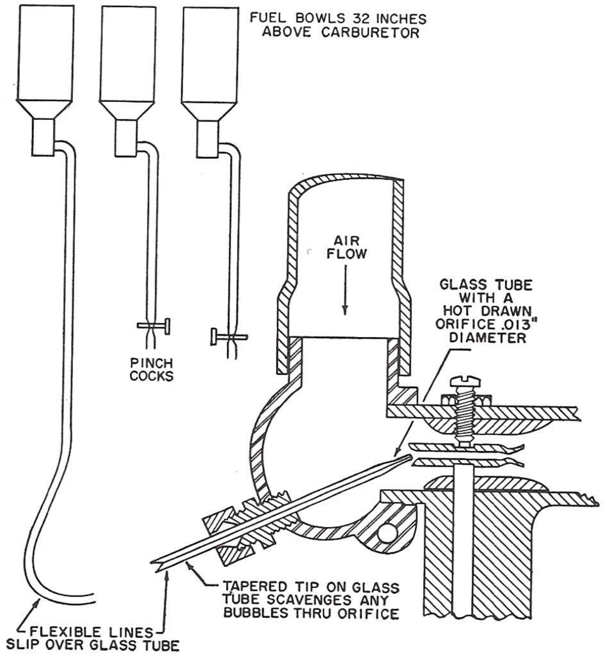

Figure 7. Simplified Fuel System Schematic.

judgement in reporting the correct meter reading.

Reducing the carburetor to its bare essentials and increasing the hydrostatic head on the fuel lines, as shown in Figure 7, eliminated many such objections to the standard carburetor.

Using the modified carburetor, the random variations in knock intensity were reduced to the level illustrated in Figure 8. As shown, the knock intensity varied less than the equivalent of ± 0.05 RON of the average rating. (The full chart scale represented 20 divisions of the standard knockmeter scale.)

Ignition Timing

For the Research method, the ignition timing is simply specified as 13 degrees before top center. A protractor scale for measuring ignition timing is provided at the front of the engine, and a rotating neon bulb is electrostatically coupled to the high-tension ignition cable in such a fashion that the bulb flashes the instant the spark plug fires.

Experience has shown that it is quite easy to accumulate errors of $\pm$ 0.5 degree crank angle as a result of reading uncertainties, and to mismatch between flywheel crank-angle reference marks and protractor divisions. Consequently, Figure 9 shows a ± 0.5 degree "probable uncertainty" in ignition timing. This could account for differences of as much as 0.30 RON when rating Fuel A in the split-head engine.

Lubricant

During the course of various experiments, it was noted that excess lubricant in the vicinity of the intake valve stem caused large temporary increases in knock intensity. Because the effect was so pronounced, it seemed desirable to determine whether oil normally

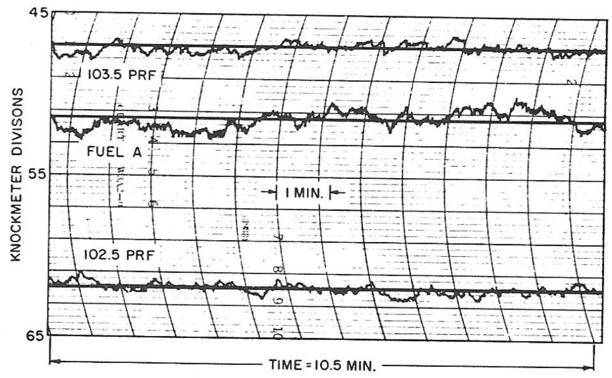

Figure 8. Knock Intensity Vs. Time.

consumed (past the piston rings or down the intake valve stem) might affect ratings. Consequently, a lubricant having no effect on knock intensity was run in a clean engine (previously disassembled and degreased in an alkaline bath). No difference in rating Fuel A was noted between the inert lubricant (a polymerized fluorocarbon) and commercial lubricating oils as long as the engine maintained reasonable oil consumption.

Effect of Instrumentation Characteristics

Amplifier and Meter Circuits

The accepted instrumentation for determining relative knock intensities is the electronic Model 501-A Knockmeter. There are at least four aspects of this device which can cause ratings to differ among various laboratories: (1) the type of maintenance it receives, (2) its amplitude linearity, (3) its frequency response, and (4) its gain and zero-level stability. Of these, only the last two were studied in detail.

The frequency response of the knockmeter is determined by a special filter circuit. If these differ from one unit to another, the relative response of the meters

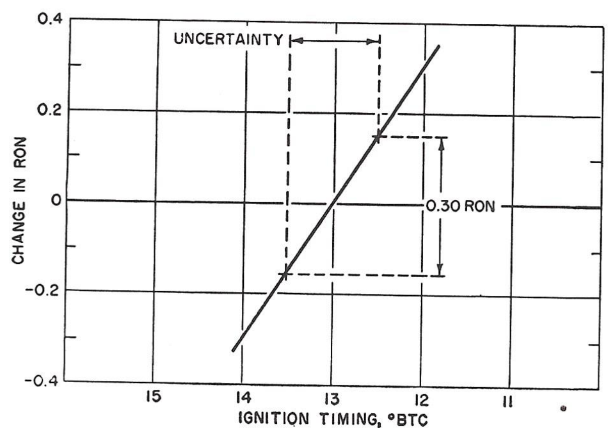

Figure 9. Effect of Ignition Timing on Fuel A.

to different hydrocarbon types will be affected. This factor is closely controlled by the manufacturer. The frequency response of five knockmeters was measured and found to be practically identical.

The knockmeter is a suppressed-zero, time-averaging type of peak voltmeter. Short-term changes in amplification factor or in zero stability of the circuits could cause variations in ratings. Long-term changes are not so important because all knock-intensity readings are directly compared to the knock intensity of a primary reference fuel.

In order to determine the gain and zero stability of the electronic circuits, a known "artificial knock signal" was introduced, and a strip-chart record made of the "apparent" knock intensity as a function of time. The circuit of the knock-signal generator is shown in Figure 10.

The inherent stability of the gain and zero adjustments of the knockmeter were shown to be excellent. An artificial knock signal, equivalent to 103 RON, was recorded for one-half hour. No observable change in the knockmeter record could be discerned.

Knockmeter Pickup

The D-1 Knockmeter pickup is specified, by the Research method, as the companion unit to the Model 501-A Knockmeter. However, there are no specifications or tolerances set forth by means of which the performance of the pickup can be judged.

In order to evaluate the performance of different pickups, consecutive ratings of Fuel A were made on the same engine by the same operators under identical engine conditions, but using different pickups. Figure 11 summarizes the data obtained on 13 different pickups. The maximum spread in ratings of Fuel A can be as much as 0.79 RON as a result of differences between these pickups.

One might expect that the more radically behaving pickups of Figure 11 would be rejected by periodic engine checks with the use of the standardization fuels,

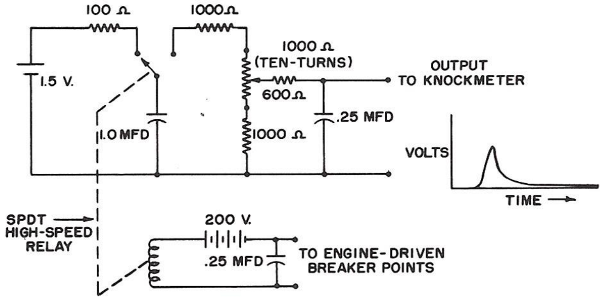

Figure 10. Knock-Signal Generator.

as suggested in the Research method. When standardization fuels are used, the Research method specifies: "If results within the tolerance of ± 0.3 octane numbers can not be obtained under standard operating conditions, the mechanical condition of the engine should be checked. 'Top overhaul.' as described in Appendix IV on Maintenance, may be required to bring about the desired results."

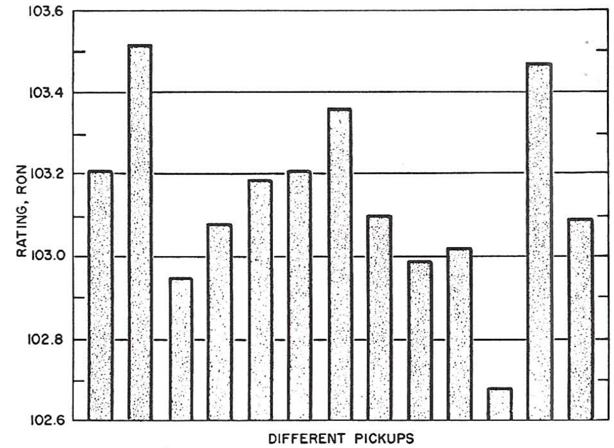

Figure 11. Effect of Different Pickups.

If the pickup were the true cause of rating errors, however, it is possible that the operator would have wasted much time on an unnecessary engine overhaul only to find that he had made no improvement in his ratings. Furthermore, it should be pointed out that random combinations of other factors reported in this paper could completely mask the effect of the pickup, leaving the operator unaware of its true performance.

Thus, there seems to be no positive method of eliminating marginal pickups. Perhaps this indicates a need for the development of a new independent criterion for judging pickup performance.

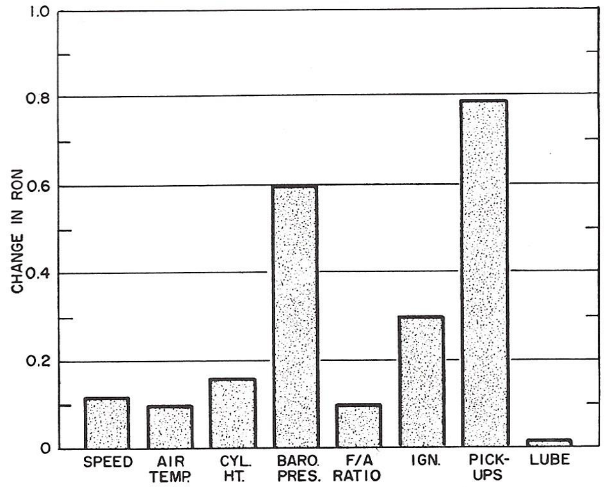

Figure 12. Relative Effects of Factors Studied.

CONCLUSIONS

Figure 12 provides a graphic comparison of the relative importance of the factors investigated to date. Obviously, many factors of possible importance have not been mentioned in this work.

Probably the reproducibility of any rating procedure utilizing an engine will be affected by engine maintenance procedures, reference fuel blending procedures, differences among engine castings, thermal gradients in combustion chambers, etc. Until a new method can be devised which will minimize the contributions of the above factors, perhaps attention should be focused on the two factors which are shown by Figure 12 to be so important in the current methods.

The knockmeter pickups have been shown to have the potential of playing a dominant role in determining reproducibility of ratings, yet no standard tests have been devised to assure acceptable performance of the pickup. The development of such tests could improve rating reproducibility significantly. Furthermore, the problem of compensating for differences in barometric pressure is still open to solution. An aggressive attack on this problem should pay off handsomely in improved ratings.

Recognition of the role of these two factors may be the next step to useful improvements in our present method.

ACKNOWLEDGMENT

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