A Statistical Study of Engine Performance Indexes Using Tractor Test Data

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A STATISTICAL STUDY OF ENGINE PERFORMANCE INDEXES
USING TRACTOR TEST DATA

by

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A THESIS
Presented to the Faculty of
The Graduate College in the University of Nebraska
In Partial Fulfillment of Requirements
For the Degree of Master of Science
Department of Agricultural Engineering

Under the Supervision of Associate Professor J. J. Sulek

Lincoln, Nebraska
June, 1966
ACKNOWLEDGMENTS

The writer wishes to express his sincere appreciation to Professor J. J. Sulek for his help and criticisms while directing this study. Also, he wishes to express appreciation to Dr. J. R. Davis, Dean of the College of Engineering and former Chairman of the Department of Agricultural Engineering, to Dr. R. W. Kleis, Chairman of the Department of Agricultural Engineering, and to Professor E. A. Olson for their help and encouragement during this study, and to the Tractor Testing personnel who supplied data required.
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INTRODUCTION

The economic selection of an engine requires knowledge of the power output, fuel economy, service conditions, and engine life. Each must be determined or estimated from the published data or from experience. Other economic and performance factors\(^1\) should be considered in an engine installation but are not considered in this study.

The power output of an engine must be matched to the load. From an economic standpoint, an engine that has too little or too much power will be more costly. An undersized engine would require more maintenance and would have a reduced life. An oversized engine would not be efficient in power use or fuel economy and would require the maintenance of a correctly matched engine.

The power characteristics are not highly important for constant load conditions. A constant load will vary little from a set value, so there would be very little torque or speed change. Then an engine that will meet the requirements for power output and economics would be suitable.

Overload conditions do require torque changes. Usually a change in torque corresponds to a change in speed, as the product of torque and speed is proportional to power. Then a properly matched engine for overloads will have a definite relationship between torque and speed. The engine should be

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able to "lug" or sustain a temporary overload. Then the selection of an engine requires an evaluation of torque and speed characteristics, other engineering factors, and economics for a suitable match of the engine to the equipment.

The fuel economy, horsepower-hours per gallon, is important from an economic standpoint. A comparison of the engine's fuel economy against the purchase price may show a higher priced engine is more economical. It has been determined that a five percent increase in fuel economy would amortize a three percent increase in the cost of a $3300 tractor over a six year period.¹ The calculations include all fixed and operating costs on the tractor and are based on 1000 hr/yr (hours per year) operating time.

The service conditions, intermittent or continuous duty, affect the service life; therefore, attention must be given to loading of the engine in relation to duty. In intermittent duty, more of the engine power can be used as the load is relieved periodically. For continuous duty the load is constant and the running time is not limited, so the continuous rating is a smaller percent of the maximum power. Some manufacturers recommend ninety percent for intermittent duty and seventy-five or eighty percent for continuous duty.²

The data shown on the manufacturers' curves and specifications are not consistent. Some of the curves are for

². Internal Combustion Engine Institute, op. cit., p,7.
dynamometer horsepower with the corresponding torque and fuel consumption curves. Others show maximum horsepower, intermittent and continuous duty curves with the corresponding torque and fuel consumption curves. Since these tests are not shown on the same base they are not directly comparable. Also, a standard form of presentation of the data is not followed.

The engine accessory load is different depending on the test reported: a bare engine, a complete engine, or a power unit. The accessory load on a bare engine is a minimum for the operation of the engine. At the other limit, all accessories normally used on the engine are functional for the power unit test. The SAE Engine Test Code, J816a, defines a bare engine with flywheel, fuel and oil pumps, etc., and the power unit with all systems functional including the clutch. The horsepower, torque, and fuel consumption are not comparable for these tests. The bare engine would show more horsepower, but this is not all available at the output shaft when an engine is placed in service. On the other hand, the power unit test shows the horsepower available for application to the load.

The atmospheric conditions that are used for data correction vary with the code under which the manufacturer is testing. These conditions vary from standard conditions, 29.92 in. Hg. and 60° F.¹ to 29.53 in. Hg. and 100° F.² for

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spark ignition engines. Diesel engine data corrections vary from standard conditions to conditions corresponding to 1500 ft. elevation and 90° F.

An engineer who must select an engine for an installation must determine or estimate the performance of the engine. The manufacturer's published data will furnish the power, torque, and fuel consumption curves for the test engine. If this information doesn't apply, or the lack of uniformity destroys confidence in the manufacturer's data, the engineer must rely on his judgment to make estimates for the performance data. Estimates may be accurate if he has wide experience with a given model, but for a model with which he has no experience estimates may be quite unreliable.

The index, a number that represents a property, is the mean value of an engine performance factor. A reliable index has a known variance and would be useful in selecting engines. It would supplement the manufacturer's data and may be the only estimate if other data are not available.

PURPOSE OF THE STUDY

The purpose of this study is: (1) to determine the reliability of power indexes in making estimates of horsepower of engines; (2) to determine the reliability of speed indexes in making estimates of operating speed of engines; (3) to determine the reliability of fuel consumption indexes in making estimates of fuel economy of engines.
REVIEW OF LITERATURE

Power Output

Several factors may be used to estimate the horsepower output of an engine. Ones in common use are breathing capacity, brake mean effective pressure, and brake horsepower per cubic inch.

An index for estimating the brake horsepower is the displacement per minute per horsepower.¹ This index equals twice the product of the displacement and rpm divided by the brake horsepower (bhp). The two in this formula gives the volume swept by the pistons since the stroke is used twice. No accuracy would be lost if the two were dropped from this formula, as the pumping work is measured in either case. The friction and pumping work is reflected in a larger value of the displacement per minute per horsepower.

The breathing capacity (C) is a modification of the formula used by Jones. The two has been dropped from his formula to give the product of displacement and rpm divided by bhp. This gives one-half the value of Jones' formula, otherwise there is no difference in the information gained from these formulas.

The brake mean effective pressure (pₚₘ) reflects the product of volumetric efficiency, brake thermal efficiency, and the fuel-air ratio at the rating point, since the brake

power is equal to the product of Joule's constant, the mass of air supplied per unit of time, the mass ratio of fuel to air, the heat of combustion of a unit mass of fuel, and the brake thermal efficiency.¹ The mass of air supplied per unit time is related to the displacement, the volumetric efficiency, and the rpm. Then \( P_m \) is equivalent to the product of volumetric efficiency, brake thermal efficiency, fuel-air ratio, Joule's constant, and the heat of combustion of the fuel.

The values of \( C \) and \( P_m \) are inversely proportional as \( P_m \) and \( C \) are related by:

\[
\frac{DN}{P_m} = \frac{bhp}{792,000} \quad \text{and} \quad \frac{DN}{C} = bhp \quad \text{then} \quad C = \frac{792,000}{P_m} \quad (4\text{-cycle engines})
\]

Since \( C \) is the inverse of \( P_m \) the properties are related.

In this study the calculations will be with \( C \).

The value of \( C \) can be calculated for any engine but will be different for any two engines unless they have the same displacement, rpm, and bhp. Then any selected value of \( C \) would give only an estimate of horsepower.

Unpublished data from the Nebraska Tractor Testing Laboratory² shows that the value of \( C \) has been decreasing as \( P_m \) has been increasing (Fig. 1). This follows as \( C \) varies inversely as \( P_m \).

². Zoz, F. M. Trends in engines. Unpublished data, Nebraska Tractor Testing Laboratory, University of Nebraska, Lincoln, Nebraska.
FIGURE 1. TRENDS
BRAKE MEAN EFFECTIVE PRESSURE

WAR
NO
TESTS

YEARS

BMEP-PSI

105
95
85
75
65
55
The brake horsepower per cubic inch (bhp/in\(^3\)) is the simplest to use in making estimates of brake horsepower. However, the accuracy is questioned as the displacement is the only factor used in these estimates.

The use of these constants, \(C\), \(p_m\), or bhp/in\(^3\), assumes a fixed value for the thermal and mechanical efficiencies of the engines, since the value is taken for the maximum power point and represents more than one engine. They also include the effects of other design variables in their value.

The reliability of the values of \(C\), \(p_m\), or bhp/in\(^3\) given in the literature is not known. They can be intentionally or unintentionally biased when based on an individual engine or the average of a small group of engines.

**Engine Speed**

The rpm and piston speed are common measures of the operating speed of an engine. Their average values have been steadily increasing (Fig. 2) as a result of the demand for more horsepower and lighter engines.\(^1\) Refinements in engine design and materials have contributed to these changes.\(^2\)

The rpm is a common term used to give the engine operating speed. The rpm must be considered when engines are applied to equipment driven by a rotating shaft.

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ever, it does not give the speed of translation which indicates engine wear and internal forces.¹

The piston speed gives the average velocity of the piston and is a function of the stroke and rpm of the engine. The higher the piston speed, the greater the inertia force, as the inertia forces increase as the square of the rpm.² Also, the piston speed increases as the first power of the stroke. Then, in design, the stroke and rpm are important. However, in operation, the stroke is fixed, so the piston speed is more indicative of the engine operating speeds and can be used as an indicator of engine life. A figure used as an upper limit to piston speed for heavy duty service is 1600 fpm.³

Torque Characteristics

The torque is a characteristic of an engine that shows its ability to handle a load.⁴ The torque characteristics of an engine (Fig. 3) are important in the selection of an engine for an installation. The peak torque will determine how well an engine will handle an overload, while the speed drop will indicate the rate of torque rise. All of the torque factors that are necessary to the good selection of

an engine are determined from the load.

When the speed drop (Fig. 3) must be limited for successful machine operation the rate of torque rise is important. If stalls are to be avoided, the peak torque must equal the load demands and must occur close to the rated speed. An example is air transport equipment—choppers, blowers, etc. If lacking in suitable torque characteristics, the engine must be larger than necessary to successfully handle the equipment.

The rate of torque rise is not highly important when the speed drop is not limited for successful operation. However, the torque curve should remain relatively flat after peak torque has been reached. For example, tillage equipment can tolerate a relatively large drop in speed in an overload situation. When the torque demand drops off with the speed, it is desirable to have the peak torque occur at a lower speed.

It is popularly believed and is supported in the literature that diesel engines have superior "lugging" ability, or will sustain an overload at a lower engine speed than other engines. "... a diesel engine is said to have better "lugging" ability; that is, it hangs to the load and continues to pull even though the speed drops off perceptibly."  

Another reference puts it this way, "This ability of the diesel to hang on under load is sometimes described as "lugging" ability. This is a definite characteristic of

the CI engine and makes it useful for heavy work."¹

A formula given for the estimation of maximum torque is \(0.7 \times \text{cu. in. piston displacement}\). The 0.7 is based on an analysis of a number of torque curves.² This formula does not indicate the speed at which maximum torque occurs, and it would be informative to know this speed.

### Fuel Economy

The fuel economy is measured as the brake specific fuel consumption of the engine. In engine tests, the fuel used is measured by weight or by volume and is reported as pounds per horsepower-hour (lb/hp-hr) or as horsepower-hour per gallon (hp-hr/gal). If consumption is determined by volume, a correction is made for temperature. Horsepower-hour per gallon is used in this study.

Full-throttle fuel economy is usually the only fuel consumption data that is published on the test engine. This information is not applicable to engines in the field as these engines operate at part loads. In any case, an engine would operate, in service, at full-throttle a small percent of the time.

The part load fuel economy estimates given in the literature are usually based on the Nebraska Tractor Test data, Varying Power and Fuel Consumption Run.³ These

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values are the averages of data taken for selected years from the Nebraska Tractor Test reports. They are usually used in conjunction with other studies and may be adjusted for a specific purpose.

The Nebraska Tractor Test Reports contain usable part-throttle information. The 85% (torque at maximum power) point of the Varying Power and Fuel Consumption Run is used to estimate fuel consumption for engines on steady load and continuous duty. The Average Line of the Varying Power and Fuel Consumption Run is used to estimate the annual fuel consumption in hp-hr/gal for tractors in general service. The 42 1/2% (torque at maximum power) point is used to predict fuel consumption of tractors in general service. The Maximum Power Run is used to make general performance comparisons of engines.

The fuel economy of the individual engine may be found from the manufacturer's specification sheet on the engine or from the Nebraska Tractor Test Reports. For conditions other than those under which it was tested, these fuel consumption figures will be approximate. This fuel economy data is comparable only if the test conditions are similar to field conditions.

The following table taken from the 1965 Agricultural Engineers Yearbook illustrates data for estimating fuel consumption. This table allows a 20% margin for type of service but makes no provision for the variability of the Nebraska Tractor Test data or the tractors to which it will be applied. It is always best whenever possible to use actual fuel consumption data.

**POWER-OUTLET SPECIFY (SIC) FUEL CONSUMPTION**

Fuel consumption, gal per belt or PTO hp-hr*

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Rated load (85% of max.)</th>
<th>3/4 of rated load</th>
<th>1/2 of rated load</th>
<th>1/4 of rated load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>0.083</td>
<td>0.088</td>
<td>0.103</td>
<td>0.153</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0.107</td>
<td>0.117</td>
<td>0.141</td>
<td>0.227</td>
</tr>
<tr>
<td>LP gas</td>
<td>0.136</td>
<td>0.152</td>
<td>0.184</td>
<td>0.277</td>
</tr>
</tbody>
</table>

*Based on analysis of 1955-1960 Nebraska Test Results, with 20 percent added as an allowance for reduced efficiency of typical tractors in farm use (69). Values apply for either wheel-type or track-type tractors.

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1. Farm machinery costs and use, op. cit., Table 5, p.253.
PROCEDURE

Performance data for this study were taken from the Nebraska Tractor Test reports and from unpublished Tractor Test data.

Data Selection

The tractors used in this analysis were selected from the 1965 Nebraska Tractor Test Summary Sheet. The models were selected on the basis of four-cycle, normally aspirated, current models tested at the Tractor Testing Laboratory and marketed in the United States, excluding tractors under 10 bhp and those with power-absorbing devices in the drive line, such as, hydrokinetic torque converters and power-shift transmissions. The tractors were subdivided into populations by fuel type. The populations include 51 gasoline, 48 diesel, and 24 propane models.

The populations defined above are small, so all of the individuals in the population are included in the calculations. Therefore, the means, variance, etc. calculated are parameters of the population. If a future population includes new models and many of the current models, the individuals defined above would be a sample of the future population. Then the means, variance, etc. could be found and could be used to make inferences about the future population.

The single tractor of each model tested represents all of the units of that model produced. This does not
allow for any variation in performance caused by manufacturing variables. It is the manufacturer's responsibility to select the tractor for the tests, so it is assumed the models in this study are above average for the model.

Data Calculations

Calculations were made using the data given on the individual test reports for the selected tractors (see the data sheet and formulas in the Appendix).

C was calculated from Test C—Operating Maximum Power, prior to 1959, and from the Maximum Power, 1959 to present.

The torque rise and speed drop were calculated from Drawbar Pull Versus Travel Speed.

The piston speed was calculated from the engine specifications and is based on rated engine rpm.

The fuel economy was taken from the PTO Varying Power and Fuel Consumption Run.

Statistical Calculations

Chi-square was used to check the normality of the distributions.

The mean, standard deviation, and coefficient of variation were calculated for each index.

Fuel economy regressions were determined from the Varying Power and Fuel Consumption Run for 100% torque, maximum power versus:

- 85% torque, maximum power
- 63 3/4% torque, maximum power
42 1/2% torque, maximum power

Average Line

Tests of significance were made with "t", "F", or Duncan's Multiple Range Test. The test used depended on the material and the information desired.

The 95% level of significance is used in this study.
RESULTS

Power

The breathing capacity (C) is normally distributed for the three fuel groups: gasoline, diesel, and propane. With a normal distribution, the location of values in the distribution can be accurately described. Then the statistical parameters of a population serve to describe the distribution.

The smaller the C value, the greater the power produced per unit displacement per minute. The mean of C for the diesel group is 11.1% greater than the mean of C for the gasoline group (Table 1). Then the average tractor model of the gasoline group is more powerful than the average diesel model for equal breathing capacity.

The mean of the propane group is 1.9% greater than the mean of the gasoline group. This difference is small, so the same average value of C would apply for both, with error less than 1% in the mean for either group.

The standard deviation of C is largest for the diesel group, 727 in³/min/bhp, and smallest for the gasoline group, 445 in³/min/bhp. The propane group has a standard deviation of 536 in³/min/bhp. There is a considerably wider confidence interval, 95% limits, between the high and low values of C for the diesel group (10216 - 7308 in³/min/bhp) than for the gasoline group (8777 - 6997) or the propane group (9110 - 6966).

The coefficient of variation of C, standard deviation
Table 1  VARIATION IN POWER, TORQUE, AND SPEED INDEXES

<table>
<thead>
<tr>
<th>INDEX</th>
<th>MEAN</th>
<th>ST'D DEVIATION</th>
<th>COEFF. VARIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D$^1$</td>
<td>G$^2$</td>
<td>P$^3$</td>
</tr>
<tr>
<td>C (IN$^3$/MIN/BHP)</td>
<td>8762</td>
<td>7887</td>
<td>8038</td>
</tr>
<tr>
<td>BHP/IN$^3$</td>
<td>.22</td>
<td>.25</td>
<td>.23</td>
</tr>
<tr>
<td>TORQUE RISE $^4$</td>
<td>10.50</td>
<td>10.88</td>
<td>9.36</td>
</tr>
<tr>
<td>SPEED DROP $^5$</td>
<td>68.95</td>
<td>61.54</td>
<td>64.60</td>
</tr>
<tr>
<td>POWER INDEX $^6$</td>
<td>75.84</td>
<td>68.09</td>
<td>69.81</td>
</tr>
</tbody>
</table>

1 Diesel  
2 Gasoline  
3 Propane  
4 Percent of torque at maximum power  
5 Percent of rated engine speed  
6 Percent of maximum brake horsepower maintained
in percent of the mean, for the groups is greatest for the diesel group, 8.3%, and least for the gasoline group, 5.6%. The propane group has a coefficient of variation of 6.7%. The gasoline group has the units closer to the mean than the other groups; therefore, the mean C of the gasoline group will give more reliable estimates of power output. With 95% confidence limits, the error for the gasoline group could be approximately ± 11% of the mean. Diesel estimates could be in error by approximately ± 17% and propane by ± 13%.

The brake horsepower per cubic inch is not normally distributed; therefore, it is not appropriate to use the analysis used with the normal distribution. The measures of central tendency and the range are used for this factor.

The gasoline group has an average of 0.25, a mode of 0.27, a median of 0.25, and a range of 0.17 - 0.32.

The diesel group has an average of 0.22, a mode of 0.23, a median of 0.235, and a range of 0.17 - 0.29.

The propane group has an average of 0.23, a mode of 0.22, a median of 0.235, and a range of 0.18 - 0.31.

The location of the C values of the individuals in the distribution can be accurately described and C is easily used. Therefore, it is the better index for making power estimates than the bhp/in³, which does not have a distribution that can be accurately described. C is the most accurate index available for making estimates, but for exact load requirements, the error in C is not acceptable.
Speed

The designer arbitrarily selects the engine rpm; as a result, it tends to be grouped around certain values and is not normally distributed. The ranges of rpm for the groups are: gasoline, 1500 - 2500; diesel, 1500 - 2500; and propane, 1500 - 2400.

The piston speed is normally distributed for all fuel groups. The gasoline group has the lowest mean piston speed of 1328 fpm, diesel the highest with 1421 fpm, and propane in between at 1386 fpm. The higher mean piston speed of the diesel group results from the increased stroke of the diesel models to make them comparable in power output to gasoline and propane.

The coefficient of variation is the greatest for the diesels, 16.4%; for gasoline, 14.5%; and least for propane, 13.1%. The 95% confidence intervals are: gasoline, 1714 - 942 fpm; diesel, 1885 - 857 fpm; and propane, 1748 - 1024 fpm.

There is not a large difference in the ranges of rpm and piston speed for the groups. But the piston speed can be described for a group with greater confidence than can the rpm. Therefore, the piston speed is a more descriptive index of a group than the rpm. Neither rpm nor piston speed is reliable in estimating the speed of the individual from the mean.

The piston speed, which is the indicator of engine internal forces and the estimator of engine life, would
be useful in determining the limit of rpm for efficient and economical operation when the limit is not specified by the manufacturer.

With this value of the rpm determined from the piston speed, C can be used to estimate the engine horsepower if the displacement is known, as the product of displacement and rpm divided by C is an estimate of bhp. C can also be used to estimate the displacement for a given bhp.

**Torque**

The torque characteristics of an engine are usually given by the torque rise and the speed drop. It would also be informative for comparison of engines to use the product of torque rise and speed drop, as this product, the power index, is a measure of the power maintained as a percent of the maximum power.

The torque rise, the corresponding speed drop, and the power index are normally distributed.

The gasoline group has the highest average torque rise and propane the lowest. There is a wide range in the torque rise for all of the fuel groups as shown by the coefficient of variation (Table 1).

The average speed drop is greatest for the gasoline group. This group also has the widest range in the speed drop of the individuals as shown by the coefficient of variation.

The gasoline group has the lowest power index, as the range of the speed drop was enough greater to offset
the higher and somewhat narrower torque rise of the group. For averages, the diesels maintain more of their maximum power than do the other groups in overload operation.

It would appear gasoline is superior in "lugging" ability, as the term is used by farmers. This is in disagreement with the authors quoted in the review of literature.

The variation within a group makes it possible for a model of one group to be superior to a model in either of the other groups in any torque index.

Fuel Economy and Engine Size

A regression analysis was used to evaluate the relationship between engine size and fuel economy. The results indicate a slight positive correlation of maximum power fuel economy and maximum power for each fuel. However, the slopes of the regression lines were so small that fuel economy was considered independent of engine size for all fuel groups (Fig. 4).

Average Line Fuel Economy

The means of the Average Line for the Varying Power and Fuel Consumption Run for gasoline, diesel, and propane groups reflect the difference in the heat content of the fuel and the engine thermal efficiency. The mean values are, in hp-hr/gal: gasoline, 9.09; diesel, 11.90; and propane, 7.20—a difference of 2.81 hp-hr/gal between gasoline and diesel means, 1.89 hp-hr/gal between gasoline
FIGURE 4. REGRESSION LINE
MAX. HP. vs MAX. HP. FUEL ECONOMY
PROPANE
and propane means, and 4.70 hp-hr/gal between diesel and propane means (Table 2).

The standard deviations of the Average Line for gasoline, diesel, and propane groups, in hp-hr/gal, are: 0.62, 1.08, and 0.52. The corresponding coefficients of variation are: 6.84%, 9.06%, and 7.27% (Table 2).

The Average Line fuel economy is frequently used to approximate the fuel economy of a tractor under normal operating conditions. An estimate of the fuel economy of an individual model using the mean of the Average Line as the estimator could be in error by ±14% for gasoline, ±18% for diesel, and ±15% for propane, 95% confidence limits.

The mean value of a fuel group is not a good index for estimating fuel economy of an individual model.

**Part Load Fuel Economy**

The mean for each load point in the Varying Power and Fuel Consumption Run was used to establish the part load fuel economy characteristics of each fuel group (Table 2 and Fig. 5). Gasoline and propane groups have similar characteristics shown by fuel economy increases with an increase in load. The diesel group is different in that the fuel economy at the 100% torque, maximum power is lower than that at the 85% point. This characteristic of the diesel group is caused by the attempt to increase power by the use of excessive fuel on the part of some manufacturers.

Fuel economy envelopes were established for each group (Fig. 5) by plotting the variation at each load point on
Table 2  VARIATION IN FUEL ECONOMY - SIX LOADS\(^1\) (TORQUE)

<table>
<thead>
<tr>
<th>LOAD (^2)</th>
<th>MEAN (HP-HR/GAL)</th>
<th>ST'D DEVIATION (HP-HR/GAL)</th>
<th>COEFF. VARIATION (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D(^3)</td>
<td>G(^4)</td>
<td>P(^5)</td>
</tr>
<tr>
<td>100 %</td>
<td>14.108</td>
<td>11.853</td>
<td>9.120</td>
</tr>
<tr>
<td>63(\frac{1}{2})%</td>
<td>13.458</td>
<td>10.164</td>
<td>7.941</td>
</tr>
<tr>
<td>42(\frac{1}{2})%</td>
<td>11.504</td>
<td>8.376</td>
<td>6.616</td>
</tr>
<tr>
<td>21(\frac{1}{2})%</td>
<td>7.722</td>
<td>5.430</td>
<td>4.471</td>
</tr>
</tbody>
</table>

\(^1\) Varying Power and Fuel Consumption Run, Nebraska Tractor Tests
\(^2\) Percent of torque at maximum power
\(^3\) Diesel
\(^4\) Gasoline
\(^5\) Propane
FIGURE 5. PART-LOAD FUEL ECONOMY DIESELS

HP-HR/GAL

0 21½ 42½ 63½ 85 100

TORQUE - %, MAX. POWER

○ MEAN
□ 95% LIMITS
the part load fuel economy curve. The deviation at the
load points gives a method of comparing the economy of an
individual to the range that exists for other models in
the same fuel group.

The fuel economy envelopes of the different fuel
groups show an overlap (Fig. 6) when plotted together.
In other words, the better gasoline engines have better
fuel economy than the poorer diesels, and the better pro-
pane engines have better economy than the poorer gasoline
models.

Approximately 68% of the individuals would be grouped
within one standard deviation of the mean at each load
point. Therefore, the overlap would not involve a large
number of engines in the population.

Since the purchaser buys an individual model, this
analysis points out the necessity for individual model
test data comparisons rather than the use of a mean to
represent a given tractor model.

The curves, standard deviation and coefficient of
variation plotted against load, show the variation in terms
of fuel economy (hp-hr/gal) and in terms of fuel economy as
a percent of the mean fuel economy. The diesel group is
twice as variable in economy as either the gasoline or pro-
pane groups in terms of standard deviation (Fig. 7). When
this economy is expressed as percent of the mean, the die-
sel group variability is much nearer the variability of
the propane and gasoline groups (Fig. 8).
FIGURE 6. ENVELOPES
FUEL ECONOMY
95% LIMITS

HP-HP/GAL

TORQUE - %, MAX. POWER

DIESEL

GASOLINE
At approximately one-half load, any fuel group (gasoline, diesel, or propane) has more models that have poorer fuel economy. The greatest variation for any fuel group occurs at mid-range of the loads as shown by the standard deviation (Fig. 7).

The theoretical advantage of metering and mixing of gaseous fuel is not substantiated by this analysis. The propane curve crosses the gasoline curve (Fig. 8) between 85% and 100% load, then remains above the gasoline curve. This indicates there are many propane tractors equipped with poor carburetion systems that do not utilize the theoretical superiority of the fuel.

The 100% load point for the diesel group (Fig. 7 & 8) shows the effects of attempts by some manufacturers to increase maximum power by operating with an excess of fuel. The standard deviation is decreasing at the 85% point. However, the curve tends to turn up between 85% and 100% load, which indicates that some models have not increased their economy between 85% and 100% load.

**Fuel Economy Predictions**

A regression analysis was used to determine the relationship between maximum power fuel economy and fuel economy at 85%, 63 3/4%, 42 1/2% and Average Line of the Varying Power and Fuel Consumption Run. The slope of the regression lines shows a strong correlation between the part load fuel economy and maximum power fuel economy for all fuel groups.
The accuracy of the prediction of part load fuel economy was determined by establishing the 95% confidence limits about the regression lines (Fig. 9 and Table 3). The largest error for the gasoline, diesel, or propane group at 85% load, 63 3/4% load, or Average Line is ± 9%. For the 42 1/2% load the errors are: gasoline 11%, diesel 17%, and propane 13%.

The regression equations give good results for the 85% and 63 3/4% loads and the Average Line but do not replace fuel consumption data on the individual. The regression equation for the 42 1/2% load does not give accuracy of prediction within limits of good practice.

Inference about Future Populations

With the data defined as a sample of a population that includes both current and future tractor models, inference can be made about the population. The distribution of individuals would likely be normal in the future, as the individuals in the sample are normally distributed. The same limitations would be imposed on the selection of the individuals used in the future samples.

The mean of C is significantly different for gasoline and diesel groups and significantly different for diesel and propane groups but is not significantly different for gasoline and propane groups. Future populations would also likely have a significant difference for gasoline and diesel groups and for diesel and propane groups (Table 4), but gasoline and propane groups would not likely be sig-
Figure 9  FUEL ECONOMY REGRESSION LINE

\[ Y_{av} = -1.08 + 0.92X \]

95% confidence limits

*torque at max. power

HP-HR/GAL - 100% , TORQUE*
Table 3  PREDICTION EQUATIONS
MAXIMUM POWER FUEL ECONOMY VS. PART LOAD FUEL ECONOMY

<table>
<thead>
<tr>
<th>LOAD</th>
<th>GASOLINE</th>
<th>DIESEL</th>
<th>PROPANE</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>-0.46 + 0.99X^2</td>
<td>1.28 + 0.92X</td>
<td>0.63 + 0.90X</td>
</tr>
<tr>
<td></td>
<td>0.247</td>
<td>0.489</td>
<td>0.184</td>
</tr>
<tr>
<td>63 3/4</td>
<td>-1.57 + 0.99X</td>
<td>0.20 + 0.94X</td>
<td>-0.91 + 0.97X</td>
</tr>
<tr>
<td></td>
<td>0.32</td>
<td>0.607</td>
<td>0.281</td>
</tr>
<tr>
<td>42 1/2</td>
<td>-243.60 + 21.26X</td>
<td>-73.96 + 6.06X</td>
<td>-250.96 + 28.46X</td>
</tr>
<tr>
<td></td>
<td>0.64</td>
<td>1.2</td>
<td>0.55</td>
</tr>
<tr>
<td>AV</td>
<td>-2.17 + 0.95X</td>
<td>-1.08 + 0.92X</td>
<td>-1.46 + 0.95X</td>
</tr>
<tr>
<td></td>
<td>0.247</td>
<td>0.466</td>
<td>0.224</td>
</tr>
<tr>
<td>CI</td>
<td>8.59 - 9.59</td>
<td>10.96 - 12.84</td>
<td>6.74 - 7.66</td>
</tr>
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</table>

1 Load in % of maximum power torque
2 X's are 100% torque, maximum power fuel economy
3 Standard error of the estimate
4 95% confidence interval at the mean
<table>
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<tr>
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<th>GASOLINE</th>
<th>DIESEL</th>
<th>PROPANE</th>
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<tr>
<td><strong>Mean</strong></td>
<td>7887</td>
<td>8762</td>
<td>8038</td>
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<tr>
<td><strong>St'd Error</strong></td>
<td>62</td>
<td>105</td>
<td>109</td>
</tr>
<tr>
<td><strong>95% CI - x</strong></td>
<td>7763-8001</td>
<td>8552-8972</td>
<td>7820-8256</td>
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<tr>
<td><strong>St'd Deviation</strong></td>
<td>445</td>
<td>727</td>
<td>536</td>
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<tr>
<td><strong>95% CI - s</strong></td>
<td>552-374</td>
<td>876-589</td>
<td>746-413</td>
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</table>
significantly different.

The gasoline and propane groups will likely be more efficient than the diesel group in power output for their breathing capacity, and the diesel group will likely have the largest spread in individual performance.

The means of piston speed are significantly different for the diesel and gasoline groups. This would likely remain the same for future populations. The difference is not significant for the diesel and propane groups or for the gasoline and propane groups. Therefore, the numerical order of these groups could be changed in future samples.

The means of the power indexes for diesel and propane groups and for diesel and gasoline groups are significantly different, so they would likely be different in future populations. The means of the gasoline and propane groups are not significantly different so would not likely be different in the future.

The means of torque rise are not significantly different for any combination of the fuel groups so would not likely be different in the future. The means of speed drop are significantly different between diesel and gasoline groups but are not significantly different between diesel and propane or gasoline and propane groups. Diesel and gasoline groups will likely be different in the future. Other groups will not likely be different.

The means of fuel economy within the fuel groups are not significantly different at the 100% and 85% load points for the diesel and propane groups. At all other points
within the fuel groups the means are significantly different. In the future the 85\% and 100\% means will not necessarily have the relative numerical order currently shown. Essentially, the average part load fuel economy for future gasoline tractors will have the same characteristics as those shown (Fig. 7). However, the fuel economy characteristics at heavy loads can change on both the diesel and propane curves.

New developments could change the picture for power output and fuel economy. Any significant changes in engine development would necessitate another study based on a different definition of a population to determine the parameters of the population and/or statistics of the sample.
CONCLUSIONS

Breathing capacity \( C \) (in \( \text{in}^3/\text{min} / \text{bhp} \)) is normally distributed. \( C \) is the most accurate index available to estimate brake horsepower, but for exact load requirements, the error in using the mean of \( C \) is not acceptable.

The piston speed is normally distributed and is more descriptive of engine speed than rpm. It is useful in determining the limit of rpm for efficient and economical operation when the limit is not specified by the manufacturer.

The power index, product of torque rise and speed drop, is normally distributed. This index is more descriptive of torque characteristics, as it gives the percent of maximum power maintained. The gasoline engines, as a group, are superior in "lugging" ability to the diesel or propane groups, but any individual in any fuel group can be superior to any individual in any other fuel group in torque rise, speed drop, or power index.

Fuel economy is independent of engine size as shown by a regression analysis. The mean of the Average Line, Varying Power and Fuel Consumption Run, for any fuel group is not a good index to represent the fuel economy of the group, as the variation in individual values is too great. The better gasoline engines have better fuel economy than the poorer diesels, and the better propane engines have

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1. The Nebraska Tractor Tests. Lincoln, Neb., Agricultural Experiment Station, College of Agriculture and Home Economics, 1965.
better economy than the poorer gasoline models. Engines should be selected on the basis of individual test data comparisons.

The diesel group is the most variable group in fuel economy and has an increase in variation of fuel economy between the 85\% and 100\% loads. The propane group does not take advantage of the theoretical superiority of the gaseous fuel. The gasoline group is the most consistent in fuel economy.

The regression equations give good estimates in predicting fuel economy at 85\% load, 63 3/4\% load, and Average Line from the maximum power fuel economy. The regression equation does not give good results for 42 1/2\% load from maximum power fuel economy.

Future populations will likely be normally distributed for breathing capacity, piston speed, and fuel economy.

The gasoline and propane groups in the future will likely produce more power per unit displacement per unit time than the diesel group.

Future populations of piston speed will likely be different for diesel and gasoline groups but not for diesel and propane groups. The gasoline and propane groups may change in numerical order.

The power index will likely be different for either diesel and gasoline or diesel and propane groups, but it will not likely be different for gasoline and propane.
groups for future populations. The torque rise will not likely be different for any group. The speed drop will likely be different for diesel and gasoline groups but not for diesel and propane or gasoline and propane groups.

For future populations, the gasoline, diesel, and propane groups will likely be different in fuel economy between groups at load points 100, 85, 63 3/4, 42 1/2, 21 1/4 and Average Line, Varying Power and Fuel Consumption Run.

The means of fuel economy will likely be different within any group for all part load points, Varying Power and Fuel Consumption Run, except between 85.5 and 100.5 load for diesel and propane. These points may change in numerical order for the group.

New developments in engine design could completely change the picture for power output and fuel economy.
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Zoz, F. H. Trends in engines. Unpublished data, Nebraska Tractor Testing Laboratory, University of Nebraska, Lincoln, Neb.
NEBRASKA TRACTOR TEST REPORTS USED IN THIS STUDY

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FORMULAS

The following formulas were used to make calculations in this study.

POWER

Brake Mean Effective Pressure

\[ p_m = \frac{792,000 \text{ bhp}}{D \text{ in}^3/\text{min/bhp}} \text{ psi} \]

Breathing Capacity

\[ C = \frac{D \text{ in}^3/\text{min}}{\text{bhp}} \]

Brake Horsepower per Cubic Inch

\[ \frac{\text{bhp}}{\text{in}^3} = \frac{\text{bhp}}{D} \]

- bhp = brake horsepower
- D = total engine displacement
- N = rpm

SPEED

Piston Speed

\[ P_s = \frac{sN}{6} \text{ fpm} \]

- s = stroke, inches
- N = rpm

TORQUE

Torque Rise

\[ T_R = \frac{L_M}{L_{\text{HP}}} \% \quad (\text{Fig. 10}) \]

Speed Drop

\[ S_D = \frac{S_M}{S_{\text{HP}}} \% \quad (\text{Fig. 10}) \]

- \( L_M \) - maximum pull, lbs.
- \( L_{\text{MP}} \) - pull at maximum power, lbs.
- \( S_M \) - speed at maximum pull, mph
- \( S_{\text{MP}} \) - speed at maximum power, mph
FIGURE 10.
SPEED-PULL CURVES
TEST NO'S 856, 858, 860

1. peak torque speed at peak torque
2. max. power torque
rated speed

PULL - lbs x 100
49
48
47

SPEED - mph
2 3 4 5 6

diesel
propane
gasoline
TORQUE (Continued)

Power Index

\[ PI = T_R \cdot S_D \% \]

STATISTICAL FORMULAS

Mean

\[ \bar{x} = \frac{\Sigma X}{n} \]

Standard Deviation

\[ s = \sqrt{\frac{\Sigma X^2 - (\Sigma X)^2/n}{n-1}} \]

Coefficient of Variation

\[ CV = \frac{100 \cdot s}{\bar{x}} \% \]

\[ \Sigma X \] - sum of the readings
\[ \Sigma X^2 \] - sum of readings squared
\[ (\Sigma X)^2 \] - square of sum of readings
\[ n \] - number of individuals

Standard Deviation of the Mean

\[ s_x = \frac{s}{\sqrt{n}} \]

95\% Confidence Interval for the Mean

\[ \bar{x} \pm t_{.05} \cdot \frac{s}{\sqrt{n}} \]

\[ t_{.05} \] - value of Student's "t"

Linear Regression

\[ Y = \bar{y} + b(X-\bar{x}) \]

\[ \bar{y} \] - mean of dependent variable
\[ b \] - regression coefficient
\[ X \] - a value of the independent variable
\[ \bar{x} \] - mean of the independent variable

Standard Error of the Estimate

\[ s_{y|x} = \sqrt{\frac{\Sigma y^2 - (\Sigma xy)^2 / \Sigma x^2}{n-2}} \]
STATISTICAL FORMULAS (Continued)

\[
\sum y^2 = \left(\Sigma (Y - \bar{y})\right)^2 \\
(\sum xy)^2 = \left[\sum (Y - \bar{y})(X - \bar{x})\right]^2 \\
\sum x^2 = \left(\Sigma (X - \bar{x})\right)^2 \\
\]

\(n\) - number of individuals

95\% Confidence Interval of Regression

\[
CI = \bar{y} + bx \pm t_{0.05} s_{y \cdot x} \\
\]

\(s_{y \cdot x}\) - standard error of \(y\) for a fixed \(x\)

Standard Normal Variable

\[
z = \frac{X - \bar{x}}{s} \\
\]

Chi-Squared

\[
\chi^2 = \sum \frac{\text{observed} - \text{expected}}{\text{expected}}^2 \\
\]

Standard Error of Difference in Treatment Means

\[
s_d = \sqrt{s^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)} \quad \text{equal variance} \\
\]

\[
s^2 = \frac{(n_1 - 1) s_1^2 + (n_2 - 1) s_2^2}{(n_1 - 1) + (n_2 - 1)} \\
\]

\[
t = \frac{\bar{x}_1 - \bar{x}_2}{s_d} \\
\]

\[
s_d^2 = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} \quad \text{unequal variance} \\
\]

\[
t^1 = \frac{\bar{x}_1 - \bar{x}_2}{s_d} \\
\]

\[
t^1 = \frac{s_1^2/n_1 t_1 + s_2^2/n_2 t_2}{s_1^2/n_1 + s_2^2/n_2} \quad \text{for comparison with } t^1 \text{ above} \\
\]

\[
t_1 - n_1 \text{df} \\
t_2 - n_2 \text{df} \\
t'\text{s} - 95\% \text{ level of significance}
Duncan's Multiple Range

\[ s_{x} = \sqrt{\frac{(\text{error mean square})}{r}} \]

\[ \text{SSR} \times s_{x} = \text{LSR} \]

SSR - significant studentized ranges

LSR - least significant range

Differences in ranked means were compared with the LSR. All means were compared.