PROCEEDINGS OF THE
EPA/INDUSTRY
QUALITY CONTROL SYMPOSIUM

DYNAMOMETER QUALITY CONTROL
CALIBRATION AND CHARACTERISTICS

JUNE 29, 1977
9:00 a.m. - 4:00 p.m.

HELD AT

EPA LABORATORY
2565 Plymouth Road
Ann Arbor, Michigan
48105

SUMMARY REPORT
EPA/INDUSTRY QC SYMPOSIUM
DYNAMOMETER CALIBRATION AND CHARACTERISTICS

Introduction

This report is a narrative synopsis of the proceedings, information, and presentations made at a Quality Control Symposium at the EPA Laboratory on June 29, 1977. This symposium was a joint effort by EPA and the automotive industry to discuss dynamometer calibration and characteristics and related quality control subjects. Approximately 40 technical representatives from the automotive industry and EPA participated in the symposium. The symposium was an informal exchange of technical information related to calibration procedures and dynamometer characteristics and their effects on emissions.

During introductory remarks to the symposium it was emphasized by Don Paulsell, Quality Control Manager for EPA, that the presentations need not be formal; informal comments relating to common problems and potential solutions in the area of dynamometer calibration and quality control are valuable to all. A general outline attached in the appendix to this report was used to structure the general flow of information and to assure complete coverage of the topics related to dynamometer quality control. This general format is anticipated for two other symposiums which are planned for the near future. The first section of this report will present an overview of the symposium. Following this synopsis a narrative description of the detailed presentations that were made will be reconstructed from the notes that were taken. The appendix of this report contains copies of formal submissions made by many of the people who gave presentations.

Synopsis of Symposium

The first three hours of the symposium were spent listening to general descriptions of the calibration procedures used at Ford, GM, Chrysler, and AMC. The presentations generally covered the type of instrumentation used to calibrate dynamometers, data collection and processing techniques and the types of calibration curves used, plus any monitoring techniques which have been implemented. Quality control criteria which are used to judge the acceptability of calibration data were emphasized. Each presentation prompted questions from the audience and related issues were discussed and explored as part of the calibration presentations. Subjects such as automatic control circuits, power absorber curves, bearing friction, temperature control, and transient response characteristics were part of those subjects covered. Following the lunch break EPA presented a general description of their calibration procedure and described some developmental techniques which are being investigated using a new instrumentation package.

The remainder of the afternoon session dealt with specific presentations on dynamometer characteristics and their effects on emission. Representatives from Volkswagen, Mercedes Benz, Honda, Ford, Mobile Oil Co., Clayton Mfg., ERDA, and EPA presented specific data quantifying the effects on emissions as related to dynamometer loading and friction. Data were presented to quantify the differences between belt drive and direct drive dynamometers as well as water brake and eddy current type power absorber units. Several techniques for the verification or translation of road load power absorber curves from on road measurements were discussed. The effects on emissions from inertia or horsepower changes were also quantified. Plots were presented which showed the effect of rear axle load, tire size, and restraining cable force on the torque required to drive the dynamometer. Measurements made from torque instrumented vehicles were also presented to compare power absorber curves of eddy current versus water brake type absorbers.

In the following paragraphs the essence of each presentation will be described. These descriptions will hopefully be accurate, but if the reader has a specific question, he is encouraged to contact the specific individual who made the presentation. While a great deal of information was exchanged during this symposium, two particular aspects of dynamometer usage were highlighted. First, there is a lack of understanding regarding the treatment of the front roll to real roll slip characteristic on a Clayton dynamometer. The basic question involves which roll speed is used to reference the horsepower which is to be set for an emissions test. The second point, which was highlighted, was that more information must be collected regarding the power absorber curve shape. Dynamometers are set for a test horsepower at 50 miles an hour but data presented indicated that power absorber curve shapes differ between dynamometer types and this difference can have an effect on emissions and fuel economy.

Descriptions of Presentations:

Ford

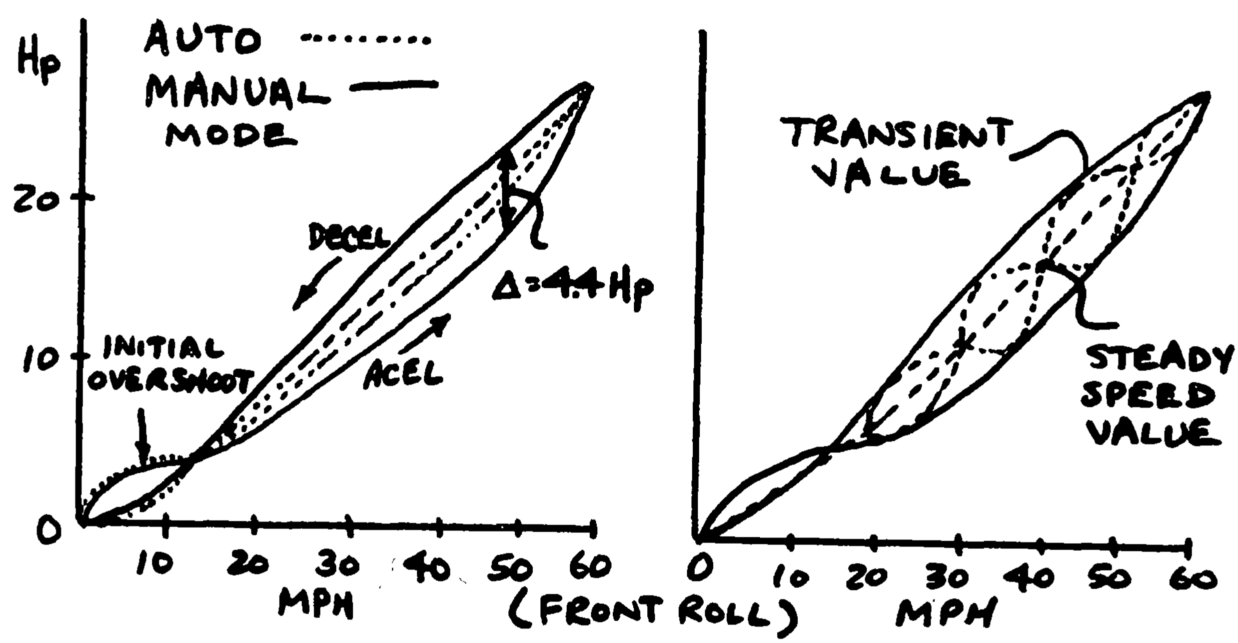
The dynamometer calibration procedure used by Ford Motor Company was presented by Mr. Bruce Gardner. Attachment 1 of the Appendix illustrates many of the points covered in the presentation. It was stated that the time required to run five data points on each of the eleven inertia weights required approximately eight hours. This procedure was done on a monthly basis. Specific inertia weights are checked on a weekly basis to verify the frictional horsepower for each individual inertia wheel. Instrumentation that is used to collect the calibration data consists of a fifth wheel which is resting on the front roller, a timing mechanism that has a resolution of ± 0.1 seconds and the indicated horsepower is read at 50 mph steady state. Ford compared the linearity of calibration curves obtained by referencing front roll and rear roll fifty mile per hour speeds. As can be seen on the plots in the attachment, the use of rear roll 50 mph to set the indicated horsepower results in increased wheel slippage at higher horsepower settings causing a non-linearity in the curve. The general consensus at the symposium was that front roll speed should be the only parameter used for performing coastdown calibrations. Ford states that they are using Clayton CTE 50 dynamometers in the manual mode of operation. They have studied the differences between the automatic and manual modes of operation and claim that the exponents of the power absorber curves are different.

General Motors

The General Motors dynamometer calibration activities were presented by John McLeod of the GM Proving Grounds. GM uses CTE 50 Clayton dynamometers. They use automatic roadload control on all certification sites. They also have a Burke Porter electric for their high altitude test cell. All calibrations are done in the automatic mode. General Motors has converted from panel meters to digital readouts. They have incorporated a thumbwheel horsepower selection switch to independently perform the inertia setting and horsepower selection. GM has also improved the roundness of the dynamometer rollers by spray welding and grinding the rollers to 8.65 ± .002" roll diameter. They incorporate an optical endcoder pickup with an output of 160 pulses per revolution on both the front and rear rollers. Their coastdown timer uses this digital pulse train in a phase lock comparator to trigger at 55 and 45 mph. The resolution of the timer is ± .01 seconds. Three calibration data points are generated at each inertia weight. One point is the Federal Register set point and the end points are ± 50% of the Federal Register set point. Three coastdowns at each point must agree within ± .3 seconds. A linear least squares fit is performed to generate the calibration data line for that inertia weight. All points must lie witin ± .3 horsepower of the line. All voltages, gains, and dead bands are checked on a monthly basis. Dead bands are maintained at .2 horsepower at zero and .4 horsepower at 50.

General Motors also runs a complete FTP in the manual mode of operation to assure that it will hold the horsepower and repeat within ± .2 horsepower. Drift problems have been detected in the automatic roadload control circuit. The problem was diagnosed and corrected by redesign of the power supply circuits. For the monthly horsepower check, the 5500 lb. inertia is checked at all three points. The slope of this line must agree within 3% of the slope of the previous calibration curve. Then each of the other inertia weights is checked at the Federal Register test point. The actual horsepower must be within ± .4 from the Federal Register value. GM has also characterized the roll slippage factor and stated that it was between .5 and 1 mph at 50. All horsepower measurements made at General Motors are made from the front roll speed signal. However the driver's trace is driven from the rear roll tach signal. The horsepower set by the automatic control circuit is referenced to the front roll. The driver verifies the horsepower by switching the digital readout to front roll speed and switches back to rear roll for the driving test. Setting horsepower by the use of front roll speed tends to load the vehicle higher than in the case of using rear roll thus increasing the emissions. The slippage factor will vary with inertia weight, horsepower setting, tire type, and the restraining force used to tie down the vehicle. This concluded GM's presentation of calibration procedure. Mr. McLeod answered several questions from the floor regarding other studies that General Motors has performed. Regarding GM's efforts to balance and true the roll diameter, they stated that they had found variances in the "out of roundness" on the order of 60 thousandths. GM had used a fifth wheel with a one foot circumference to measure roll diameters by turn ratios, but found that the method was unacceptable because of fifth wheel bounce caused by a seam in the roller. A question was asked about the difference in PAU curves and transient response comparing the manual and automatic modes of operation. Mr. Juneja of GM said the hysteresis between the accel and decel modes in the manual operation was severe. In the automatic mode the power absorber curve is electronically forced to second order and the hysteresis was reduced by 70%. Figure 1 illustrates the tests that were performed and the hysteresis curve that was generated on an XY plotter using the different accel/decel rates. The initial overshoot

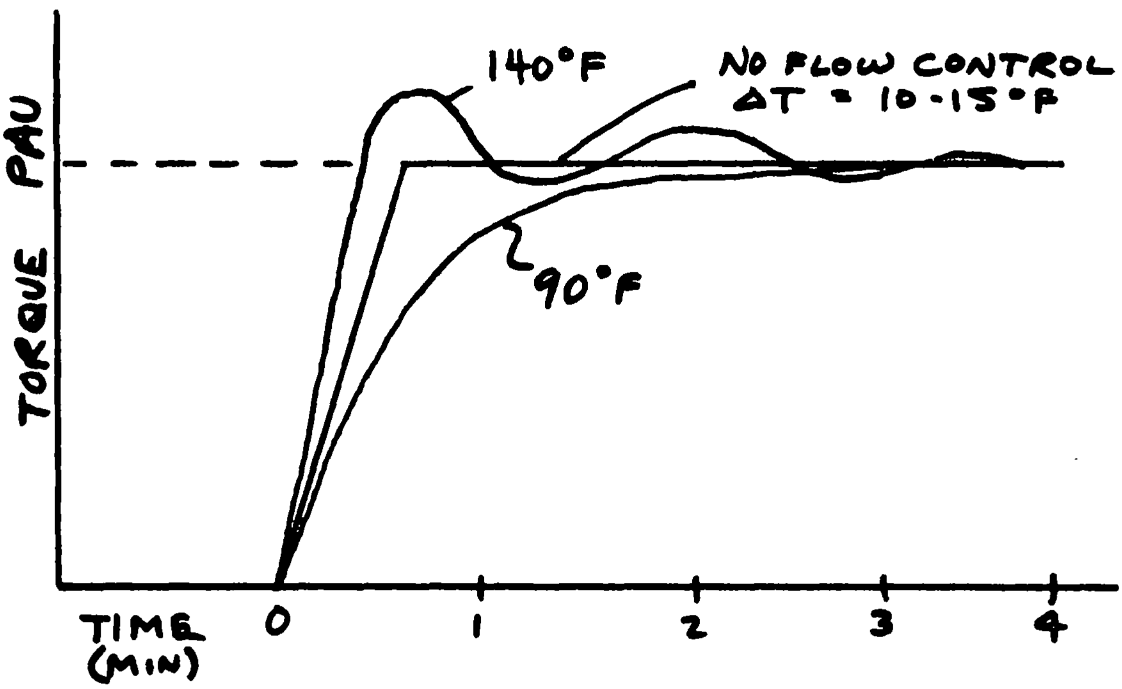
FIGURE 1.



ACEL/DECEL RATES OF 1,3,5 (FT./SEC.²)
AUTOMATIC CONTROL REDUCES HYSTERESIS.

from the zero mph speed is caused by the transient redistribution of water in the power absorber unit. It was mentioned that this transient can be reduced if the heat exchanger is cleaned. Mr. Berg from Mercedes Benz said that the hump is not apparent on the Schenk eddy current type of dynamometer. During the discussion of hysteresis phenomena, temperature control was mentioned as a major cause of hysteresis, GM had also conducted studies in the manual mode looking at hysteresis with the same amount of water and varying the temperature. They found that increasing the temperature causes the power absorber load to go up but did not necessarily decrease the amount of hysteresis. Mr. Hasegawa from American Honda claimed that the elimination of flow control on the heat exchanger cooling water produced a critically damp response to a transient change in speed. Figure 2 illustrates the characteristics reported for

FIGURE 2.



TORQUE RESPONSE VS TEMPERATURE/FLOW

different temperature conditons. GM was asked if they had ever tried to quantify bearing friction for each individual flywheel and what they found across all their dynamometer sites. Mr. Juneja said they did not see a cumulative effect, and that it varies among all their dynamometers. A Ford participant reiterated that they had seen the same thing.

However, Mr. Hasegawa from Honda said they can plot bearing friction versus the number of bearings that have been engaged. Mr. Juneja claimed that bearing friction is about 60% due to the windage effect, in other words, the shear drag on the flywheel, and that 40% could actually be attributed to the bearing itself. Mr. Meyers from Clayton commented that they are changing to a low friction bearing which has a looser fit in their new 125 lb. inertia weight package. Mr. Paulsell from EPA stated that if the torque measurement during the coastdown interval is integrated, it has a significant effect on the precision of the data. Data illustrating this effect were presented in a later talk. It was also stated that the exponent of the power absorber unit remains closer to three and more consistent from dyno to dyno in the automatic mode than it did in the manual mode. The question of setting the horsepower based on front roll speed resulted in a lengthy discussion about the effect of using front or rear roll speed as a reference signal for the horsepower setting. Clayton has incorporated a vehicle adjustment potentiometer on their new unit to allow the operator to select either front or rear roll speed as the reference signal.

Chrysler

Following a ten minute break the Chrysler calibration procedure was presented by Frank Johnson and Bob Rice.

Chrysler is in the process of converting to digital meters and digital thumbwheel horsepower selectors. They use the automatic mode for the Federal Register horsepower values. However, they have added potentiometers to decrease the sensitivity of setting these values. For any special horsepowers the manual mode is used. The dynamometer is calibrated in the automatic mode. All data signals are taken on line by a PCS computer system with a timing device that has ± .2 second resolution. Chrysler uses the CTE 50 direct drive dynamometers. All speed signals are calibrated using a master strobotach. Chrysler claimed that they didn't care for the use of a fifth wheel but rather had developed an optical light beam sensor with a light and dark timing tape.

Chrysler calibrates dynamometers on a monthly basis at the Federal Register set point. Each calibration check must agree within ± .1 of a horsepower or ± .1 of a second whichever is greater. For special horsepowers a 4 point line is generated in the manual mode. The Clayton tachometer signals are fed to the PCS computer and set points for 55 and 45 are trimmed. This timing tape, which is an alternating yellow and black, is placed on the roll and has a resolution of 14 pulses per rev as a square wave. The set point voltages must be set within ± two millivolts. A short discussion followed with a man from the Allen Park

Ford test lab on the use of a single pulse per rev to trigger a time base generator for doing coastdown calibrations. It seemed that he had relatively good success using this method. Chrysler performs a 3 point dead weight at 15, 25 and 40 foot lbs. Hysteresis is nulled by tapping the PAU with a rubber mallet. For the emissions test they use the rear roll signal for setting the horsepower. In addition to the calibration presentation some additional data were submitted by Chrysler and can be found in the Appendix.

AMC

The last presentation of the morning was by Mr. Al Morris from the American Motors Corporation.

AMC performs monthly calibrations using 4 points - 6, 12, 18 and 24 indicated horsepower. Like Chrysler, they also use a strobotach for setting speeds with an optical sensor and four reflective strips. This optical signal is passed to an amplifier where the 55 and 45 mph set points are triggered. Their timing device is a resolution of ± .1 seconds. They run 4 points per inertia weight and 2 runs per setting must agree within ± .3 seconds. On the monthly horsepower check, they perform one 12 horsepower coastdown across all inertia weights. If the coastdown differs from theoretical by more than ± 1 second, the calibration is repeated. Changes can be detected at levels of ± .5 seconds based on quality control monitoring data. AMC uses the automatic roadload control feature of the Clayton dynamometer. They also use a grooved front roll which consists of cross-hatched one inch spiral grooves that are machined into the roller surface. They claim that this pattern does not completely eliminate the slip but it does reduce it. They restrain the vehicle loosely with a cable winch on each side.

In response to a question about the use of the new Clayton digital readouts for visually triggering the coastdown calibration, Mr. Dave Stevenson of Clayton claimed that the new Weston's have a gate time of a tenth of a second. This would effect the accuracy of visual triggering at the 55 and 45 mph set points. Based on the presentations given it would appear that visual triggering of a coastdown timer does not permit the achievement of the desired precision and accuracy. Automatic triggering would be the preferred mode of operation.

EPA

The final presentation on calibration procedures was made by Don Paulsell for EPA.

EPA uses Clayton ECE 50's and all are operated in the automatic road load control mode. Individual potentiometers on the Clayton design have been replaced by Kelvin Varley thumbwheel precision dividers to permit independent selection of inertia and horsepower values. EPA's basic calibration procedure consists of performing coastdowns at 3 indicated horsepower settings for each inertia weight. The settings used are 4, 8, and 14 HP. At least squares regression line is fit through the 3 points and the slope and intercept are calculated for each inertia. These values are printed in the calibration tables. A copy of this table is illustrated in the appendix. It was pointed out that the slopes for the inertia weights vary from about .85 for a low inertia weight to .95 for the 5500 lbs. This is significant in light of recent developments at EPA which have shown that the slopes of the lines should be equal to 1. This aspect was discussed later in the presentation.

The calibration data sheet is shown in the appendix and is divided into 7 basic parts. All the calibration data about the dynamometer are entered on the first line of the data sheet. The next three sections quantify the front and rear tach generator calibrations, the load cell linearity with the voltage to frequency conversion factor, and the shape of the power absorber curve by counting steady state torque/speed data. A typical calibration data set is shown in the appendix. The final three sections of the calibration data sheet are used for entering the torque, speed, and time data for the three indicated horsepower values. Each line is used for an inertia weight.

EPA's dynamometer calibration instrument consists of a voltage comparator which has precision set points for 55 and 45 miles per hour. The front roll tach voltage is fed to the comparator at a nominal value of 5 volts equals 50 miles per hour. This voltage is trimmed using a synchronous (1800 rpm) strobotach at 46.3 miles per hour. The voltage comparator gates three counters -- a timer that has a capacity of 99.999 seconds and two six digit counters, one for integrating torque and one for integrating speed. The torque voltage is passed through a voltage frequency converter and the speed signal comes from a mag pick up and 60 tooth gear that is externally coupled to the outboard shaft of the front roller. The accuracy of the set point comparator is plus or minus .1% and the precision of the entire system based on repeative ramp measurements is plus or minus ten milliseconds. It was pointed out that the use of integrated torque and integrated speed greatly improves the precision and the accuracy of the calibration data used in the regression equations.

The next view graph which is also illustrated in the appendix presented some of the reduced calibration data. One notes in the far right column that the data very closely fit the regression line with the average percent of point deviation being less than a .1%, the maximum value is about one quarter of a percent. Based on these typical deviations, EPA uses a plus or minus 1% of point criteria for assessing the validity of the curve fit. In the calibration table the frictional horsepower is also printed out for each inertia weight. One will also note that 150 lbs. has been subtracted from the total inertia. This is done to account for the absence of the rear roll inertia in the coastdown measurement. As one can see in the general equation, the slope of the inertia calibration line is very close to 1.0000, averaging .9973. If the actual horsepower is the sum of the indicated horsepower plus the friction due to bearings then one would conclude in theory that this slope should be 1.0, since there is no explanation as to why frictions should increase simply by increasing the power absorber setting. Using this method of analysis, frictional horsepowers for each inertia weight were compared across all six dynamometers used by EPA for certification testing. The next table in the appendix illustrates these data. As one can see from the table, the frictional horsepowers are relatively consistent from dynamometer to dynamometer, maximum difference being about .3 horsepower.

The calibration procedure also assesses the rear roll frictional horsepower and the exponent of the power absorber curve. One can see that the typical rear roll frictional horsepower is about .14 and that the exponent of the Clayton power absorber unit averages 3.05 plus or minus about 3%. The next plot in the appendix shows the effect of deleting the 150 lbs. in the inertia calculation and makes the intercept of the calibration line equal to the frictional horsepower of the inertia weight. The representative from Clayton pointed out that the actual inertia of a rear roll ECE-50 dynamometer is 154 lbs. This value also varies depending upon the dynamometer type.

In order to assess whether the frictional horsepower can be assigned to the engagement of the specific inertia wheels a special analysis was performed on the data presented in the preceding table. Differences in total friction were subtracted to come up with a composite value for each of the five inertia wheels. These data are summarized in the table in the appendix. One can observe that the frictional values per inertia wheel are consistent within each dynamometer and are relatively uniform across dynamometers. The magnitude of the values increase with increasing inertia, this being attributed to the weight of the wheel or the aerodynamic drag which would be associated with the size of the wheel. Mr. Juneja of General Motors claimed that their analysis showed that about 60% of the total frictional horsepower could be attributed to aerodynamic drag. Since the analysis only provided one estimate for the frictional horsepower of the 1750 lb. trim assembly, a best estimate approach was used by taking the average values obtained for each wheel and going through a summation process by deleting these from the total friction. The next table in the appendix illustrates the extremely good uniformity of this type of analysis. The average frictional horsepower was on the order of 1.2 with a coefficient variation that did not exceed 5%. The analysis also showed that in most the single point estimate will be within about 1% of the best fit estimate for the trim frictional horsepower. The final exercise in this breakdown of friction by bearing involved counting the number of bearings engaged for each inertia configuration. This analysis is also presented in a table in the appendix and showed that the average frictional horsepower per bearing was approximately .11Hp.

Following the formal presentation of the EPA calibration procedure, the discussion turned to the subject of front to rear roll slippage and which rollers should be used for setting the horsepower. Mr. Paulsell said that EPA presently sets the horsepower based on rear roll speed and that the horsepower check at a steady 50 miles an hour showed that the automatic control system was controlling within .25 horsepower of the thumbwheel set value. GM asked for clarification on the point of using automatic roadload control which is typically driven from the front roll speed signal. It was explained that the thumbwheel is trimmed at 10 horsepower at a rear roll speed of 50 miles an hour. Since this value is near the middle of the Federal Register table, the values below 10 are slightly higher than they would be if they were set by front roll 50 and the values above 10 are slightly lower. However, as stated previously, these values are within .25 horsepower of the thumbwheel set value which seems to be acceptable for the total system precision. GM representatives stated that the front roll speed signal is used for calibrating the dynamometer as well as setting the horsepower for the test. The dynamometer set up has a switch for transferring to front roll speed for setting the horsepower and then back to rear roll speed for driving the trace. It was agreed that the use of front or rear roll speed signals was a subject of major impact on the use of dynamometers and that the resolution and specification of the preferred method would be undertaken by the EPA Laboratory. This concluded the formal presentations and the discussions of dynamometer calibration procedures. After a short break, the remainder of the symposium was devoted to specific presentations on various studies which had been performed to quantify the effects on emissions of different dynamometer characteristics.

Dyno Characteristics - Effects on Emissions

The first speaker was Heinrich Schlumbohm from Volkswagen. He presented a short synopsis of an SAE paper (No. 770139) entitled "Torque Measurements and Mechanized Driver for Correlating Exhaust Emission Test Facilities." The paper deals with the use of a torque instrumented vehicle to compare torque versus speed curves of different dynamometers. The essence of the paper points to the fact that although dynamometers can be set to the same value at 50 miles an hour, the shape of the power absorber curve off of the set point can vary considerably from dyno to dyno. VW recommends that EPA have a master dynamometer or a typical power absorber exponent and that any other dynamometer be adjusted to match this exponent within limits.

The effect of curve exponent on emissions was discussed briefly. It was noted that the LA4 consumes about 65% of the work performed in driving the inertia. The other 35% is absorbed as roadload horsepower. Mr. Juneja from General Motors stated that a one horsepower error at 50 miles an hour has an effect of approximately 1/2% for CO_2 and NOx emissions. A 10% error in horsepower was shown to produce a 4% difference on NOx and a 2% difference on CO_2 for the FTP on one vehicle. For the highway cycle, a 10% error leads to approximately a 4% change in CO_2 emissions. It was also stated that a 10% error in the inertia weight setting translates to approximately an 11% change in NOx emissions and a 3-1/2% change in CO_2 emissions. These numbers were quoted from another SAE paper written by Mr. Juneja, (No. 770136) entitled "A Treatise on Exhaust Emission Test Variability."

The next presentation came from Mr. Jim Chase of the Bartlesville Energy Research Development Center. He presented some data showing the difference in power absorber curve shapes between the direct drive dynamometer versus the belt drive. It was clarified that the belt drive dyno is the older style with the single pulley sheath and not the variable speed dynamometer. Two curves presented are shown in the appendix. These are for 4,000 lbs. and show that the belts produce a higher horsepower above 50 and a lower power below 50. He concluded that the direct drive dynamometer curve simulates the roadload curve closer. He stated that their new direct drive dynamometer produced a lower fuel economy value for the highway fuel economy cycle on a vehicle that they have been testing for several years. The belt drive produced an average of 21.6 miles per gallon while the direct drive yielded an average of 19.8 mpg. He also stated that they saw no difference in the LA 4 test using bag 2 as their comparator.

The third speaker for the afternoon was Wolfgang Berg from Mercedes-Benz. Mercedes has also built a vehicle and instrumented it with torque wheels. The presentation of Mr. Berg's has been translated into English and has been included in its entirety in the appendix. He discussed several projects that have been performed with this instrumented car. The comparison of two Schenk dynamometers, one with a water brake power absorber, and one with an eddy current power absorber was made. They also studied the effect on the torque required to drive the dynamometer as a function of rear axle load. He also stated the tire type has a dominant effect on the required torque. They tested several tire sizes at different speeds and the data are shown in the presentation in the appendix. One study of specific interest to anyone testing vehicles and using cables as restraining devices is the quantification of the effect of cable force on drive line torque. This instrumented vehicle is also used to compare two different types of dynamometer power absorbers. Both comparisons are shown in Fig. H on a Schenk dynamometer. The water brake power absorber had a roll spacing of 17.7 while the eddy current power absorber had a roll spacing of 21.7. The vehicle was also used to compare the effects of start-up break away torque on the road measurements to the dynamometer measurements. This is shown on Fig. E in the appendix. It was stated that the cable winch used for the test of cable restraining force effect was the same style winch used at EPA. Six hundred pounds of force are transmitted by two ratchet clicks of the winch and this translates to approximately a 10% change in axle drive torque.

The next presentation was made by Jerry Meek of Ford Motor Co. One of the special studies Ford is performing is doing continuous dynamometer coastdowns and looking at the force versus deceleration equation for the power absorber curve. This report is included in the appendix. Basically they found that frictional torque follows a first order function with an intercept value of .7 to 1.3 at 0 speed and values of 2.5 to 7.5 at 50 miles per hour.

The final presentation, made by Mick Leiferman of EPA, was basically a briefing on a contract study that EPA is funding for the feasibility/testing of a flatbed dynamometer. Two different vehicles, a 4500 lb. and a 2200 lb. inertia weight, with three different tire types, will be studied on this dynamometer. He emphasized that the project is several months away from the starting date and that they considered the project to be very preliminary in nature.

This concluded the presentations in the afternoon session on dynamometer characteristics. The chairman thanked everyone for their attendance and very worthwhile presentations. It was announced that these seminars would be conducted monthly and that the second seminar would be scheduled for July 27, 1977 and would deal with the subject of calibration gas management and traceability. The symposium was adjourned at 4:30 p.m. and several of the attendees stayed for a short tour of the laboratory. John Meyers from Clayton Manufacturing discussed some of the differences between their new equipment and the older style control systems at one of the new installations in the EPA laboratory. This dynamometer is being characterized by the EPA Quality Control Development Staff and a report will be released when this study is completed.

This summary was written by Don Paulsell, acting chairman for the symposium, and reflects data taken from notes made during the session. Formal submissions are shown in the Appendix.

APPENDIX

SUBMISSIONS TO SYMPOSIUM

EPA/INDUSTRY QC SEMINAR
DYNAMOMETER CALIBRATION AND CHARACTERISTICS

JUNE 29, 1977
9 A.M. - 4 P.M.

GENERAL OUTLINE

I. Introduction

II. Calibration Procedures

- A. General Description
- B. Instrumentation
- C. Data Collection and Processing
- D. Calibration Curve Use and Monitoring
- E. QC Criteria

III. Discussion of Calibration Procedures

- A. Automatic Control Circuits
- B. Power Absorber Curves
- C. Bearing Friction

LUNCH 12 - 1

IV. Dynamometer Characteristics and Effects on Emissions

- A. Inertia Sensitivity
- B. Horsepower Sensitivity
- C. PAU Exponent Effect
- D. Restraining Force
- E. Roll Spacing/Surface Finish
- F. Speed Calibration and Front/Rear Slip Effects
- G. Roll Revs. Statistics

V. Summary Comments

ATTENDANCE ROSTER: QC SYMPOSIUM ON DYNOS. HELD @ EPA LAB - WEDNESDAY, JUNE 29, 1977

Frank E. Johnson
Chrysler
12800 Oakland
Highland Park, Mich. 48203
956-6285

Arnold T. Weibel
Chrysler
12800 Oakland
Highland Park, Mich. 48203
956-2036

V. J. Potochnik
Chrysler
12800 Oakland
956-5060

Jim O. Chase
E.R.D.A. Energy Research Center
P. O. Box 1398
Bartlesville, Oklahoma 74003
918-336-2400

D. F. Sougstad
GM Proving Grounds
Milford, Mich. 48042
685-5176

Alan A. Morris
American Motors
14250 Plymouth Road
Detroit, Mich. 48232
493-2960

J. F. Meek
Ford Motor Co.
Room 1049, Bldg. 5
P. O. Box 2053
Dearborn, Mich. 48127
322-3197

Ken Takahashi
Nissan Motor Co., Ltd.
560 Sylvan Ave.
Englewood Cliffs, New Jersey 07632
201-871-3555

Mark Oleszkowicz
Ford Motor Co.
Allen Park Test Lab
1500 Enterprise Dr.
Allen Park, Mich. 48101
322-4486

Al Papay
Mercedes-Benz
One Mercedes Dr.
Motvale, New Jersey 07645
201-573-2642

Robert E. Rice
Chrysler
Chelsea Proving Grounds
Chelsea, Michigan
475-8651 X381

Carlo Cucchi
Fiat
Parklane Tower, West 1 Parklane Blvd.
Dearborn, Michigan 48126
336-3515

William G. Mears
Mobil Research & Development Corp.
Paulsboro, New Jersey 08066
609-423-1040 X2442

Al Roddan
AESI
7300 Bolsa Ave.
Westminster, Calf. 92603
714-897-0333

Art C. Bodeau
Ford Motor Co.
17000 Oakwood Blvd.
Allen Park, Mich.
313-323-3221

Hienrich W. Sohlumbohm
Volkswagen of America
818 Sylvan Avenue
Englewood Cliffs, New Jersey 07632
201-894-6522

S. Hasegawa
American Honda
3947 Research Park Drive
Ann Arbor, Mich. 48104
994-8441

R. Wass
Burke Porter Machinery
730 Plymouth Road
Grand Rapids, Mich. 49505
616-459-2061

Wolfgang Berg
Daimcer-Benz
7 Stuttgart-60 Mercedesstr.
711-302-3717

Ramesh Panchal
Burke Porter Machinery
730 Plymouth Road
Grand Rapids, Mich. 49505
616-459-9531

Jim Groat
J. Lee Hackett
23550 Haggerty
Farmington, Mich.
478-0200

Robert Coff
Ford Motor Co.
17000 Oakwood. Blvd.
Allen Park, Mich.
322-4197

Bruce R. Gardner
Ford Motor Co.
21500 Oakwood Blvd.
Dearborn, Mich. 48124
322-5227

N. E. March
Chrysler
P. O. Box 118
Detroit, Mich. 48288
956-4892

Jon R. McLeod
GM Proving Ground-Vehicle Emission Lab
Milford, Mich. 48042
685-6084

James Henry
Subaru Technical Center
3132 W. Adams
Santa Ana, Calif. 92704
714-751-0344

Dave Stevenson
Clayton Manufacturing
4213 N Temple City Blvd.
El Monte, Calif. 92173
213-443-9381

Reg Rice
Clayton Manufacturing
P. O. Box 189
Southfield, Mich. 48037
354-2220

John D. Myers
Clayton Manufacturing
24750 Swanson Rd.
P. O. Box 187
Southfield, Mich. 48037
313-354-2220

K. Sakai
Toyota
1012 Pontiac Trail
Ann Arbor, Mich. 48105
769-1350

M. N. Pearsall
EPA

Bob Gilkey
EPA

Glen Thompson
EPA

Doug Berg
EPA

T. Hosaka
Honda

PRESENTED BY BRUCE GARDNER
FORD MOTOR COMPANY

EPA/INDUSTRY QUALITY CONTROL SEMINAR - DYNAMOMETERS

AEFEO Multiple Inertia Dynamometer Calibration Technique

- Formerly coastdowns at each inertia and horsepower setting were used. This was possible since there were only "Cookbook" horsepowers.
- Track coastdown values now can be applied to dynamometer tests. The need now is for a broad spectrum of actual horsepowers for each inertia setting.
- AEFEO has chosen to run Clayton CTE-50 dynamometers in the manual mode.
- One coastdown at each of five indicated horsepowers are run at each inertia (Display 1).
- A linear regression is run on each set of five data points, relating indicated horsepower to actual dynamometer horsepower (5500 + is the same as 5500).
- The resulting curves (Display 2) are applied by the operator.
- The analysis (Display 3) includes a goodness of fit criteria (± 0.3 calculated vs. measured).
- A comparison is made to the previous calibration on the basis of friction horsepower (far right column), and the T test on regression slopes.
- Weekly coastdowns use ± 0.5 HP limits. These also apply to the friction horsepower.
- Comparing with the EPA procedure shows this technique to be a better fit of the data (Display 4).
- Comparison to using front roll speed to set indicated horsepowers, shows that some non linearity is explained by the slippage between front and rear rolls (Display 5).

FKM/maj

6/28/77

ATTACHMENT 1

AERODYNAMOMETER COASTDOWN CALIBRATION

LINE #		EQUIPMENT I.D.	DATE MM	DD	YY	TIME	CELL
1350	DATA	"TC24"	6	16	77	1750	1

INDICATED HP NOMINAL VALUE

IA	LINE #		24.0 HP	20.0 HP	16.0 HP	12.0 HP	8.0 HP	
5500+	1351	DATA	24.–	20.–	16.–	12.–	8.–	IND. HP
ALL)	1352	DATA	11.1	13.3	16.2	20.6	28.2	CSTD. TIME
5500	1353	DATA	24.–	20.–	16.–	12.–	8.–	IND. HP
ALL)	1354	DATA	11.1	13.1	16.2	20.5	27.7	CSTD. TIME
5000	1355	DATA	24.–	20.–	16.–	12.–	8.–	IND. HP
3-4-5)	1356	DATA	10.3	12.3	15.–	19.1	26.4	CSTD. TIME
4500	1357	DATA	24.–	20.–	16.–	12.–	8.–	IND. HP
2-3-5)	1358	DATA	9.3	11.1	13.5	17.3	23.9	CSTD. TIME

IA	LINE #		18.0 HP	15.0 HP	12.0 HP	9.0 HP	6.0 HP	
4000	1359	DATA	18.–	15.–	12.–	9.–	6.–	IND. HP
-3-5)	1360	DATA	11.1	13.1	15.9	20.1	27.9	CSTD. TIME
3500	1361	DATA	18.–	15.–	12.–	9.–	6.–	IND. HP
-3-4)	1362	DATA	9.5	11.2	13.3	16.8	22.9	CSTD. TIME
3000	1363	DATA	18.–	15.–	12.–	9.–	6.–	IND. HP
-3-4)	1364	DATA	8.2	9.7	11.8	14.9	20.5	CSTD. TIME

IA	LINE #		13.0 HP	11.0 HP	9.0 HP	7.0 HP	5.0 HP	
2750	1365	DATA	13.0	10.9	9.0	7.0	5.0	IND. HP
3-4)	1366	DATA	9.9	11.7	13.9	17.0	22.5	CSTD. TIME
2500	1367	DATA	13.0	10.9	9.0	6.9	5.0	IND. HP
-2-3)	1368	DATA	9.0	10.4	12.5	15.5	20.1	CSTD. TIME
2250	1369	DATA	13.0	11.0	9.0	7.0	4.9	IND. HP
2-3)	1370	DATA	8.2	9.4	11.4	13.9	18.3	CSTD TIME
2000	1371	DATA	13.0	11.0	9.0	6.9	5.0	IND. HP
1-3)	1372	DATA	7.3	8.4	10.2	12.7	16.6	CSTD. TIME
[illegible]0	1373	DATA	13.0	11.0	9.0	7.0	5.0	IND. HP
(3)	1374	DATA	6.4	7.5	8.9	11.0	14.4	CSTD. TIME

TECHNOLOGIST [illegible]

LIGHT VEHICLE DYNAMOMETER 50 MPH HORSEPOWER CALIBRATION

CELL 1 DATE 6/16/77

	WITHOUT AC FACTOR		WITH AC FACTOR		REGRESSION	
INERTIA	ACTUAL HP	INDICATED HP	ACTUAL HP	INDICATED HP	SLOPE	INTR
1750	7.7	5.3	8.5	6.0	0.8709	1.4
2000	7.5	5.2	8.3	5.8	0.8536	1.2
2000	8.3	5.8	9.1	6.6	0.8536	1.2
2250	8.8	6.1	9.7	6.9	0.8739	1.6
2500	9.4	6.6	10.3	7.4	0.8532	1.4
2750	9.9	7.1	10.9	8.0	0.8520	1.3
3000	10.3	7.3	11.3	8.2	0.9030	2.0
3500	11.2	7.7	12.3	8.7	0.9224	2.6
4000	12.0	9.0	13.2	10.1	0.9142	2.0
4500	12.7	9.2	14.0	10.3	0.8941	2.1
5000	13.4	9.8	14.7	11.0	0.8936	2.2
5500	13.9	9.8	15.3	11.0	0.8829	2.5
5500+	14.4	10.4	15.8	11.7	0.8806	2.3

REGRESSION: (50 MPH INDICATED HP) = (50 MPH ACTUAL HP) X (SLOPE) - (INTR)

DYNAMOMETER 50 MPH HORSEPOWER CALIBRATION EVALUATION

CELL 1

INERTIA	PRESENT CALIBRATION 6/16/77 REGRESSION SLOPE	INTR	CORREL COEF	STD ERR SLOPE	IND HP FROM CURVE[1] MAX	MIN	MEAN	PREVIOUS CALIBRATION 5/21/77 REGRESSION SLOPE	INTR	CORREL COEF	STD ERR SLOPE	T-RATIO[2] ON SLOPE	FRICTION HP[3] PRESENT	PREVIOUS	DIFF
1750	0.8709	1.4	1.000	0.017	0.1	-0.0	0.0	0.8340	1.1	1.000	0.014	1.670	2.4	2.3	0.1
2000	0.8536	1.2	1.000	0.016	-0.1	-0.0	-0.0	0.8417	1.2	1.000	0.015	0.540	2.3	2.4	-0.1
2250	0.8739	1.6	1.000	0.019	0.1	0.0	0.0	0.8586	1.4	1.000	0.017	0.589	2.7	2.7	0.0
2500	0.8532	1.4	1.000	0.018	-0.1	-0.0	-0.0	0.8699	1.6	1.000	0.019	-0.642	2.8	2.8	0.0
2750	0.8520	1.3	1.000	0.016	0.1	-0.0	0.0	0.8672	1.4	1.000	0.018	-0.630	2.8	2.7	0.0
3000	0.9030	2.0	1.000	0.021	0.1	-0.0	-0.0	0.8894	2.0	1.000	0.021	0.463	3.0	3.2	-0.2
3500	0.9224	2.6	1.000	0.026	-0.1	-0.0	-0.0	0.8901	2.5	1.000	0.024	0.913	3.5	3.8	-0.3
4000	0.9142	2.0	1.000	0.021	-0.1	0.0	-0.0	0.8980	2.1	1.000	0.022	0.533	3.0	3.4	-0.3
4500	0.8941	2.1	1.000	0.018	0.1	0.0	-0.0	0.8496	1.8	1.000	0.015	1.902	3.5	3.8	-0.3
5000	0.8936	2.2	1.000	0.018	-0.1	-0.0	0.0	0.8896	2.3	1.000	0.019	0.152	3.6	3.8	-0.2
5500	0.8829	2.5	1.000	0.019	0.3	-0.0	0.0	0.8601	2.5	1.000	0.019	0.828	4.1	4.4	-0.3
5500+	0.8806	2.3	1.000	0.018	-0.2	0.0	-0.0	0.9033	2.8	1.000	0.022	-0.799	4.0	4.2	-0.2

* INDICATES SIGNIFICANT SHIFT IN CALIBRATION. NOTE ANY DYNO REPAIRS/REPLACEMENTS.

1. BASED ON MEASURED 50 MPH IND HP DIFFERENCES FROM REGRESSION
2. BASED ON POOLED S.E. OF PREVIOUS & PRESENT REGRESSION SLOPES, T-CRITICAL IS 3.182 FOR DF = 3 AT 95% CONFIDENCE
3. FRICTION HP TAKEN FOR STD LT VEHICLE ACTUAL 50 MPH HP

MEASURED VS CALCULATED 50 MPH INDICATED HORSEPOWER

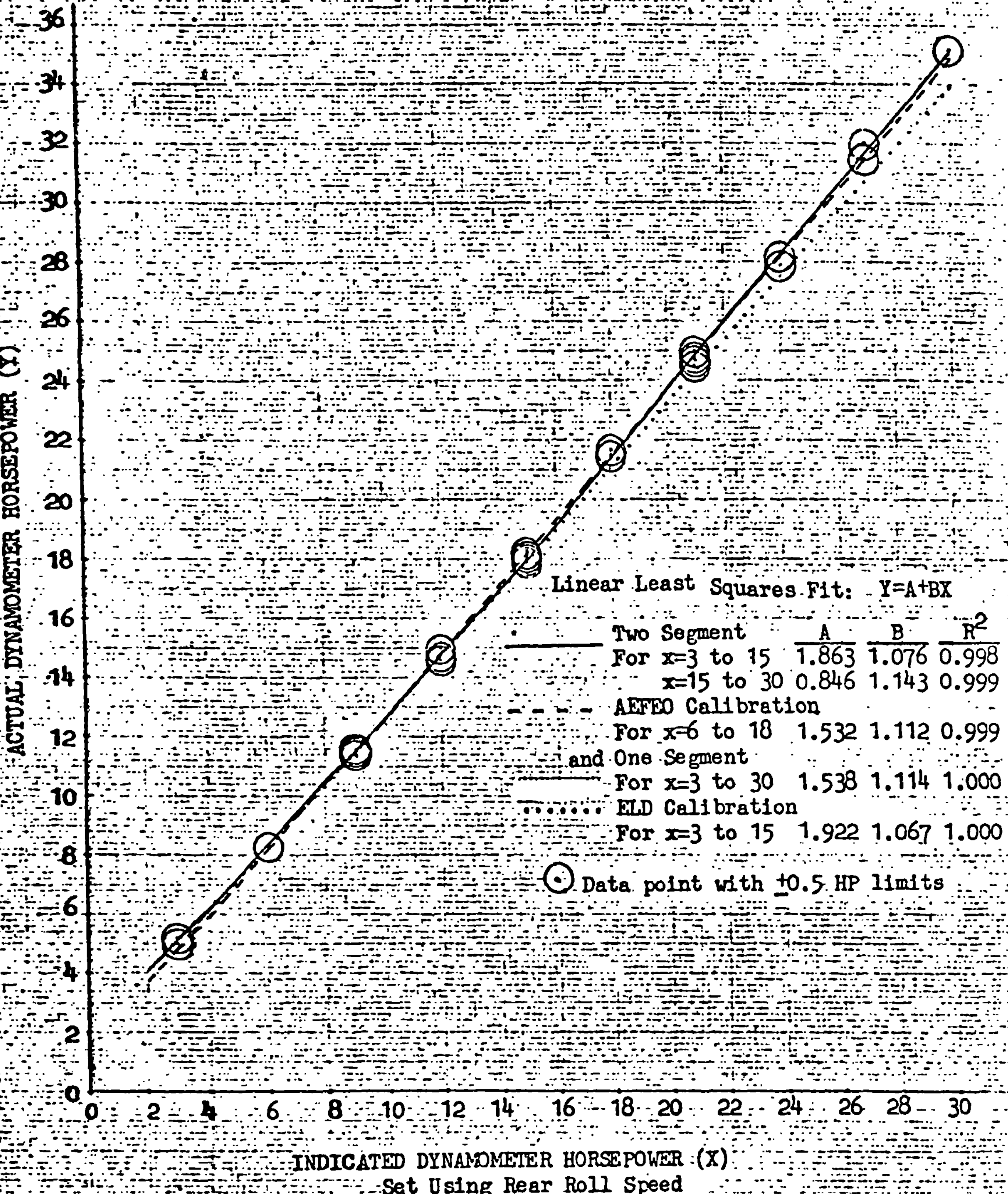
INERTIA	1750	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500	5500+
MEASURED	13.0	13.0	13.0	13.0	13.0	18.0	18.0	18.0	24.0	24.0	24.0	24.0
INDICATED	11.0	11.0	11.0	10.9	10.9	15.0	15.0	15.0	20.0	20.0	20.0	20.0
HORSEPOWER	9.0	9.0	9.0	9.0	9.0	12.0	12.0	12.0	16.0	16.0	16.0	16.0
	7.0	6.9	7.0	6.9	7.0	9.0	9.0	9.0	12.0	12.0	12.0	12.0
	5.0	5.0	4.9	5.0	5.0	6.0	6.0	6.0	8.0	8.0	8.0	8.0
CALCULATED	13.1	13.0	13.0	13.0	13.1	18.1	18.0	18.0	24.1	24.1	24.1	24.2
INDICATED	10.9	11.1	11.1	11.0	10.8	15.0	14.9	15.0	19.9	19.9	20.0	19.8
HORSEPOWER	9.0	8.9	8.9	8.9	8.9	11.9	12.1	12.0	16.0	15.9	15.7	15.9
	7.0	6.9	7.0	6.9	7.1	9.0	9.0	9.1	12.0	12.0	11.9	12.0
	5.0	5.0	4.9	5.0	5.0	6.0	5.9	6.0	8.1	8.1	8.2	8.1
DIFFERENCE	-0.1	0.0	0.0	0.0	-0.1	-0.1	-0.0	-0.0	-0.1	-0.1	-0.1	-0.2
	0.1	-0.1	-0.1	-0.1	0.1	0.0	0.1	0.0	0.1	0.1	-0.0	0.2
	0.0	0.1	0.1	0.1	0.1	0.1	-0.1	0.0	0.0	0.1	0.3	0.1
	-0.0	-0.0	0.0	-0.0	-0.1	-0.0	-0.0	-0.1	0.0	-0.0	0.1	0.0
	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	0.1	0.0	-0.1	-0.1	-0.2	-0.1

NOTE: MAX ALLOWABLE DIFFERENCE IS 0.3 HP

DONE

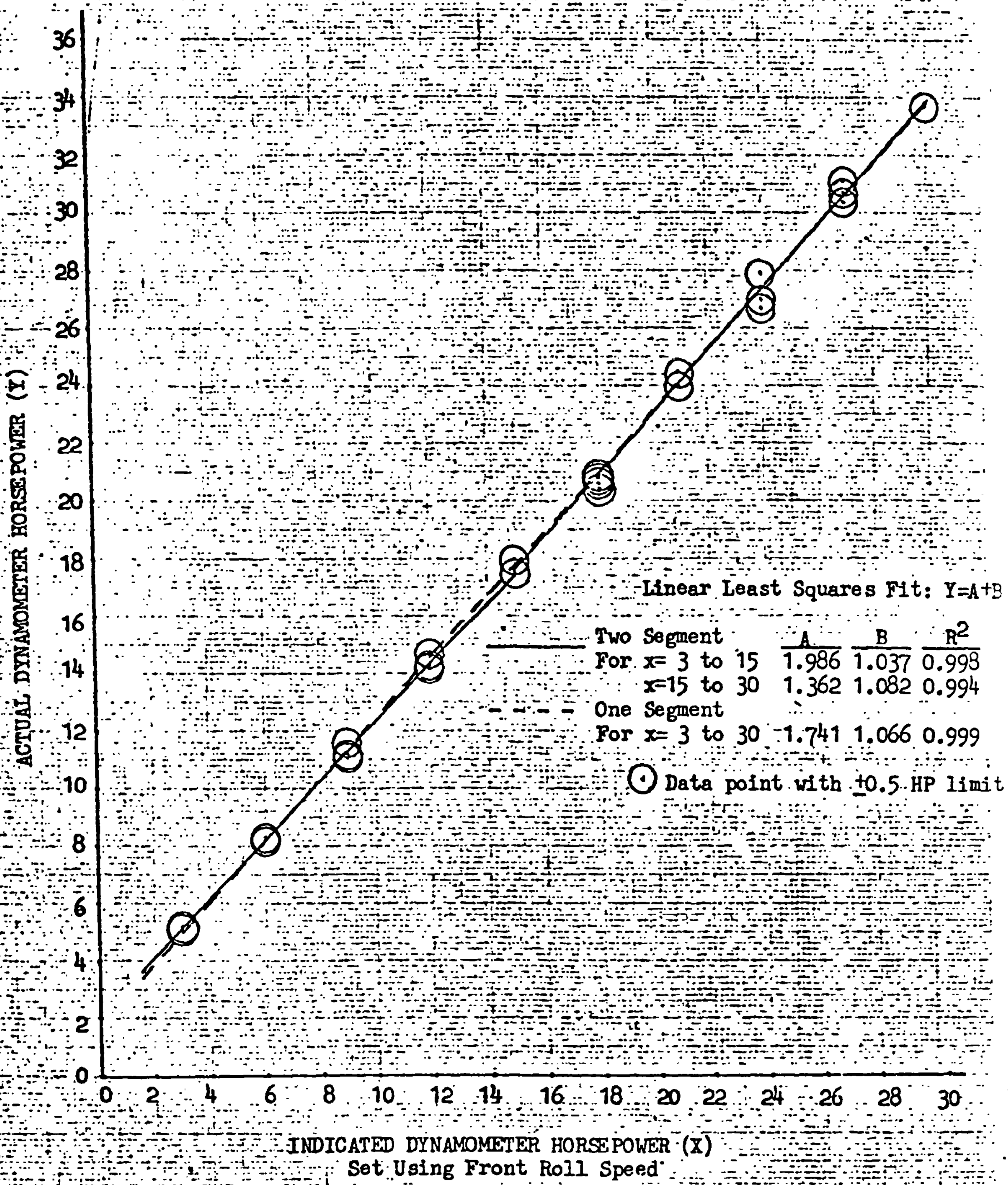
DISPLAY

Road Load Linearity Study
Cell 2 At 4000 LBS Inertia
IHP Set Using Rear Roll Speed



2-1-77

Road Load Linearity Study
Cell 2 At 4000 LBS Inertia
IHP Set Using Front Roll Speed



2-9-77

SUBMITTED BY ARNOLD T. WEIBEL
EMISSION DEVELOPMENT TESTING
CHRYSLER CORPORATION

7/5/77

AUTOMATIC/MANUAL ROAD LOAD COMPARISON

These data were obtained on a dynamometer with a 125 pound increment inertia weight assembly. It was also equipped with the new thumbwheel horsepower control. A complete recalibration was performed each week on the dynamometer. These data cover a three week span. The same thumbwheel settings were used with each set of coastdowns. In the manual mode the setting sometimes drifted, but indicated horsepower was recorded after a repeatable absorbed horsepower value was obtained. These data are very consistent from week to week, with the manual mode giving absorbed horsepower values a few tenths of a horsepower higher than the automatic mode. See Attachment #1.

Data which were obtained on dynamometers equipped with the normal automatic road load control are included for comparison. These data are indicated horsepower values which correspond to the book horsepower plus AC factor obtained by performing coastdowns in both manual and automatic mode. Manual values are calculated from a straight line fit of the coastdown data. Automatic values are read from the Clayton meter after the road load control has been adjusted to give the book value absorbed horsepower.

Two points became apparent during this study. Paying careful attention to all details in calibration of the road load control improves correlation between automatic and manual mode. Removal and calibration of the Clayton torquemeter has minimized non-linearity in the torque cell calibration and also improved manual/automatic correlation.

Dynamometers #21 and #22 have had their meters removed and replaced with a recalibrated meter. The most recent coastdowns on these dynamometers show very good manual/automatic correlation. The previous calibration on #21 (6/20/77) was not performed with due care and this is evident by comparison with coastdown data before and after this date.

These data are given in Attachment #2. In most cases indicated horsepower is greater in automatic mode.

A brief study was made of the speed difference between the front and rear rollers under various conditions. These measurements were made on a new dynamometer with thumbwheel road load power control. Speeds were read from the digital speed meters. The data are shown in attachment #3.

Dept. 5140
ATW

AUTOMATIC ROAD LOAD

INERTIA	INDICATED H.P.	ABSORBED HORSEPOWER 5/13/77	5/16/77	5/23/77
5000	16.0	18.52	18.52	18.52
	14.0	15.82	15.98	15.82
	6.0	8.25	8.39	8.34
4000	16.0	18.69	18.40	18.40
	12.0	14.46	14.12	14.29
	4.0	6.13	6.10	6.23
3500	14.0	16.61	16.34	16.35
	11.2	13.45	13.28	13.63
	4.0	6.04	5.87	6.07
2125	10.0	12.17	12.17	12.41
	8.0	10.08	10.08	10.08
	4.0	5.87	5.76	6.03

MANUAL ROAD LOAD

INERTIA	INDICATED/ABSORBED HORSEPOWER 5/14/77	5/17/77	5/26/77
5000	16.1/19.22	16.1/18.98	16.0/19.46
	13.9/16.15	13.5/16.15	13.4/16.5
	5.8/8.21	6.0/8.39	5.9/8.34
4000	16.1/18.98	16.7/19.28	16.1/19.28
	12.0/14.81	12.4/14.63	12.2/15.0
	4.0/6.13	4.0/6.20	4.0/6.20
3500	13.9/16.87	14.0/16.87	14.1/17.14
	11.0/13.28	11.4/13.80	11.3/13.98
	4.0/5.94	4.0/6.04	4.0/5.94
2125	10.0/12.65	10.1/12.65	
	8.4/10.94	8.0/10.41	
	4.0/5.81	4.1/6.15	

Dept. 5140
ATW
7/5/77

Attachment 2

ROLL 21 DATE:	5-20-77 Manual	Auto	6-20-77 Manual	Auto	6-24-77 Manual	Auto
3000			8.41	8.8	8.26	8.5
3500	8.88	9.00	9.19	9.5	9.13	9.1
4000			10.06	10.4	10.0	10.0
4500	10.69	10.75	10.31	10.9	10.53	10.8
5000	11.34	11.35	10.82	11.6	11.03	11.4
5500			11.06	11.8	11.33	11.6

ROLL: DATE:	22 6-29-77 Manual	Auto	23 6-21-77 Manual	Auto	25 6-17-77 Manual	Auto	26 6-14-77 Manual	Auto
3000	8.26	8.25	8.80	9.30		-		-
3500	8.70	8.7	9.49	10.0		-		-
4000	10.01	10.0	10.60	10.8	10.04	10.5	10.46	10.4
4500	10.49	10.3	10.96	11.3	10.58	11.3	10.92	10.9
5000	10.86	10.9	11.48	11.8	10.95	11.3	11.72	11.7
5500	11.02	11.0	11.72	12.0	10.55	11.5	11.79	11.9

Dept. 5140
ATW
7/5/77

FRONT/REAR ROLLS SPEED COMPARISON

A. Speed Difference versus Roll Speed

4000 lb. Inertia - Book H.P. w/AC

Rear	Front	Diff.
55.0	53.8	1.2 MPH
50.0	49.1	0.9
45.0	44.2	0.8
40.0	39.4	0.6
35.0	34.5	0.5
30.0	29.6	0.4
20.0	19.8	0.2

B. Speed Difference versus PAU Load

Rear Rolls = 50 MPH

Dial H.P.	Front Speed	MPH	Indicated H.P. Front	Indicated H.P. Rear
5	49.2	0.8	4.8	4.8
10	49.0	1.0	9.5	9.6
15	48.8	1.2	13.8	14.1
20	48.6	1.4	18.2	18.7
25	48.2	1.8	22.3	23.2

C. Speed Difference versus Tire Pressure

4000 lb. Inertia - Book H.P. w/AC
Rear Rolls = 50 MPH

Tire Pressure	Front Rolls Speed
25 PSI	48.7 MPH
35	48.8
45	48.9

Dept. 5140
ATW
7/5/77

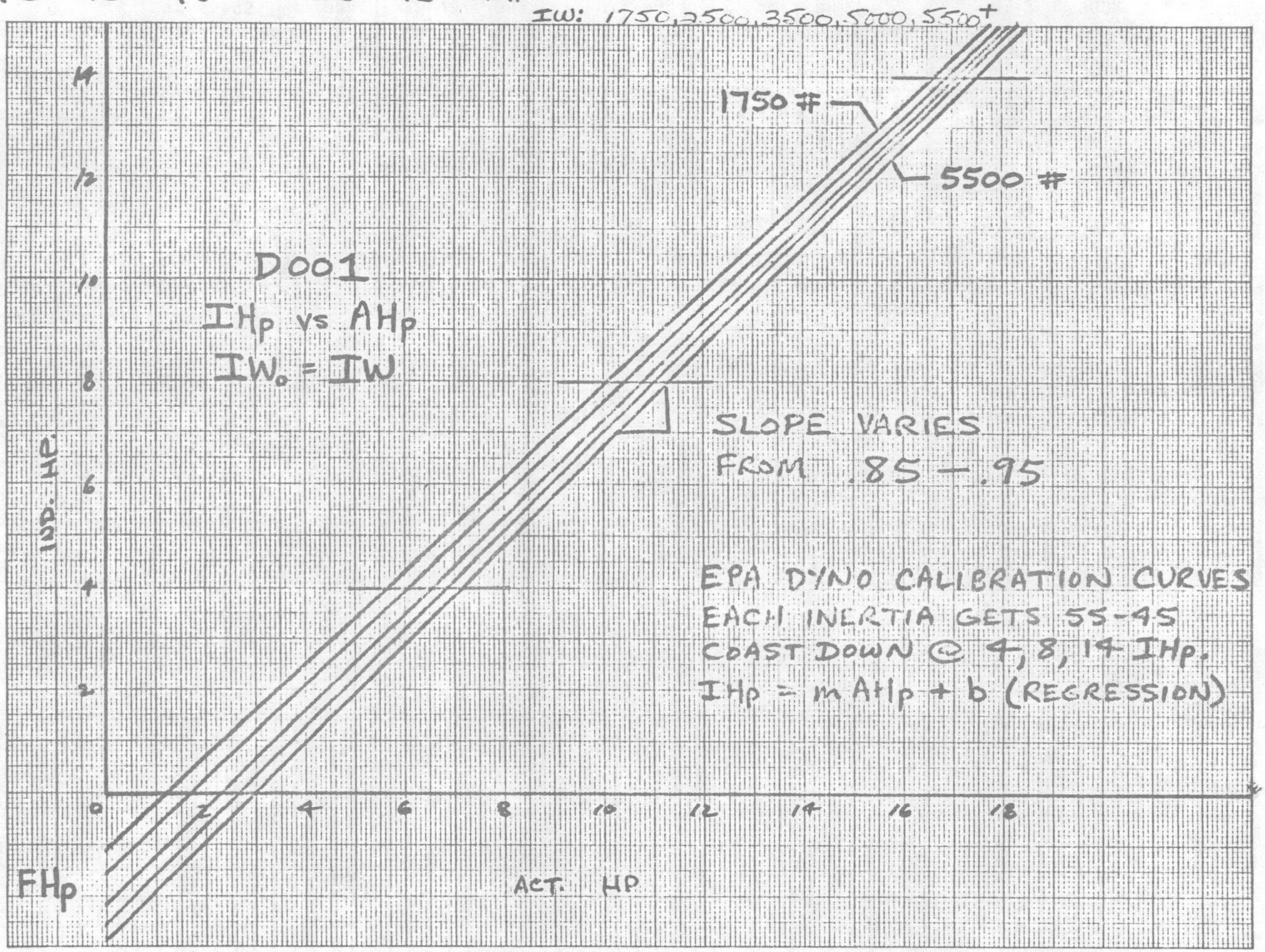
EPA CALIBRATION PROCEDURE

AND DEVELOPMENTAL ANALYSIS

VIEWGRAPHS DISCUSSED BY DON PAULSELL

DYNO - D001

12-10-76 55-45 MPH



DYNAMOMETER CALIBRATION DATA SHEET

DYNO SITE	DYNO EPA PID	CALIBRATION MODE	CALIB. DATE MM DD YY	CALIB. TIME HH MM SS	OPERATOR EPA I.D.	COASTDOWN SPEED RANGE	P.A.U. INERTIA	REAR ROLL 55-45 Δt		01
			– –	: :		–				

COMMENTS: 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

	02

SPEED CALIBRATION — TORQUE CALIBRATION — P.A.U. CURVE

SPEED MTR MPH	FRONT TACH VDC	REAR TACH VDC	TRUE SPEED RPM	TORQUE MTR FT-LBS	LOAD CELL VDC	TORQUE COUNTS CPS	SPEED MPH	SPEED COUNTS	TORQUE COUNTS	TIME SECS		
												03
												04
												05
												06
												07
												08
												09
												10
												11
												12
												13

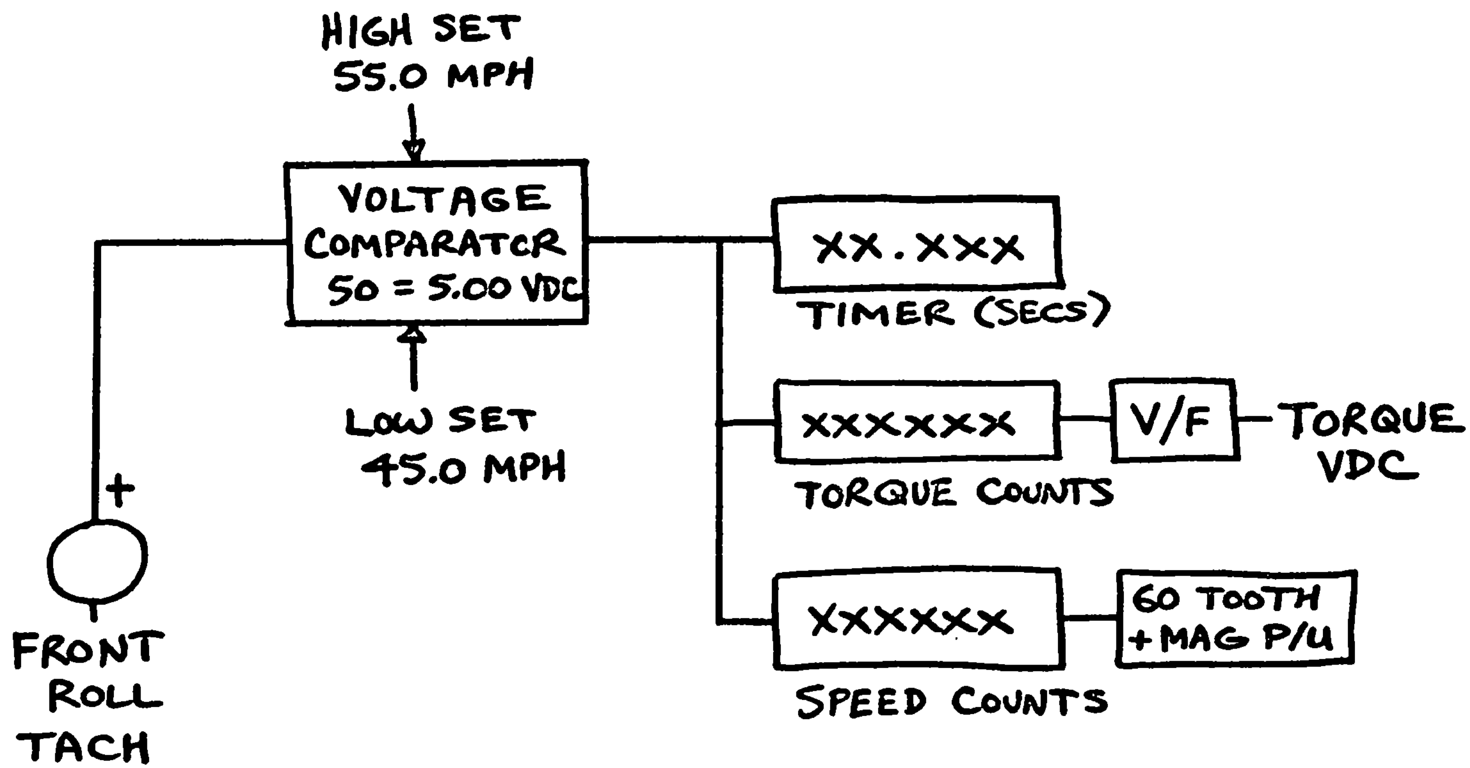
05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

COASTDOWN CALIBRATION DATA

INERTIA LBS.	TORQUE COUNTS	SPEED COUNTS	ΔT SECS	TORQUE COUNTS	SPEED COUNTS	ΔT SECS	TORQUE COUNTS	SPEED COUNTS	ΔT SECS		
											14
											15
											16
											17
											18
											19
											20
											21
											22
											23
											24

05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

DYNAMOMETER CALIBRATION INSTRUMENT



ACCURACY = ±.1%

PRECISION = ± 10 MS

********* PROCESSED: JUL 7, 1977 AT 10:40:29

DYNAMOMETER SITE: D001
DYNO EPA PID:
CALIBRATION MODE: AUTO
CALIBRATION DATE: 4/26/77
CALIBRATION TIME: 0: 0: 8
OPERATOR ID: 13925
SPEED RANGE: 55.00-45.00 MPH
REAR ROLL FHP: 0.143 HP
AVG. RR DELTA T: 63.75

```
******                                  ******
****   DYNAMOMETER CALIBRATION AND        ****
****                                      ****
****   COASTDOWN   DATA   ANALYSIS        ****
******                                  ******
```

```
DDDDDD    000000    000000    11111
 DD  DD  00    00  00    00  11  11
 DD   DD 0      0  0      0      11
 DD  DD  00    00  00    00      11
DDDDDD    000000    000000   11111111
```

COMMENTS: SPEED CALIBRATION FROM 4-22-77 /BAD 115 VAC PLUG

**** SPEED METER CALIBRATION ****

FROLL SPEED (MPH)	MTR RDG MPH	REAR TACH V-DC	REAR VDC% DIFF	FRONT TACH V-DC	FRONT VDC% DIFF
10.04	10.0	2.25	0.20	1.42	0.33
15.16	15.0	3.41	1.24	2.15	0.59
20.12	20.0	4.54	1.09	2.84	0.07
24.88	25.0	5.61	-0.07	3.51	0.02
29.70	30.0	6.73	-0.10	4.21	0.53
34.33	35.0	7.77	-1.14	4.85	0.18
39.48	40.0	8.95	-0.36	5.56	-0.12
44.47	45.0	10.12	0.15	6.28	0.14
49.33	50.0	11.25	0.20	6.97	0.19
54.22	55.0	12.40	0.40	7.62	-0.34
58.65	60.0	13.45	-0.17	8.26	-0.13

FRONT VDC = 0.1410 * MPH (7.05 @ 50)
REAR VDC = 0.2246 * MTR (11.23 @ 50)

*** POWER MTR CALIBRATION ***

MTR RDG FTLB	TORQ V-DC	TORQ VDC% DIFF	TORQ HZ% DIFF	TORQ MTR% DIFF
5.0	0.287	-1.55	-1.78	0.0
10.0	0.574	-1.55	-1.61	0.0
15.0	0.873	-0.18	-0.41	0.0
20.0	1.164	-0.18	-0.32	0.0
25.0	1.455	-0.18	-0.20	0.0
30.0	1.752	0.17	0.22	0.0
40.0	2.330	-0.09	-0.15	0.0
50.4	2.920	0.17	0.24	0.80
60.0	3.480	-0.52	-0.41	0.0
75.2	4.380	0.17	0.25	0.27
91.0	5.260	0.24	0.22	1.11

FIT DATA (handwritten bracket: rows 5.0–50.4)

HERTZ = 58.2392 * FT-LBS
VDC = 0.0583 * FT-LBS
VDC = 2.6237 @ 45 FT-LBS

*********** POWER ABSORPTION CURVE DATA **********

SPEED CNTS	TORQ CNTS	SECS	AVG SPEED MPH	AVG TORQ FTLB	CALC IHP	PAU CURV IHP	PAU CURV %DIFF
3957.	641.	9.924	10.26	1.11	0.08	0.10	-13.26
6026.	1480.	10.232	15.16	2.48	0.28	0.31	-8.98
7776.	2637.	9.842	20.33	4.60	0.69	0.73	-4.74
9944.	4156.	10.214	25.05	6.99	1.30	1.34	-3.59
11621.	6073.	9.946	30.07	10.48	2.33	2.30	1.49
13270.	8093.	9.867	34.61	14.08	3.61	3.48	3.72
15568.	10702.	10.050	39.86	18.28	5.39	5.27	2.32
17541.	12908.	10.057	44.88	22.04	7.32	7.47	-2.07
19327.	15826.	10.030	49.59	27.09	9.94	10.02	-0.80
21444.	19125.	10.186	54.18	32.24	12.92	13.00	-0.62
23013.	22305.	10.044	58.96	38.13	16.64	16.68	-0.28

FIT DATA (handwritten bracket: rows 9944.–23013.)

PAU CURVE FOR 4000. IW: IHP = K * (N**M)
BETWEEN 25 AND 60 MPH K = 0.1025E-03
M = 2.9434

*********************** POWER ABSORPTION CALIBRATION DATA ***********************

WT LBS	TORQ CNTS	ROLL CNTS	DELTA T	AVG TORQ	AVG S	MEAS AHP	MEAS IHP	CALC FHP	CALC IHP	% DEV
1750.	11836.	36544.	18.872	10.77	49.83	5.63	3.97	1.66	3.97	0.042
	13355.	20386.	10.538	21.76	49.78	10.09	8.02	2.07	8.02	-0.035
	14110.	12365.	6.389	37.92	49.80	16.63	13.98	2.66	13.97	0.008
2000.	13169.	40485.	20.907	10.82	49.83	5.81	3.99	1.82	3.99	-0.069
	15131.	23125.	11.950	21.74	49.80	10.16	8.01	2.15	8.01	0.057
	16129.	14097.	7.285	38.02	49.80	16.67	14.01	2.66	14.01	-0.013
2250.	14587.	44986.	23.214	10.79	49.87	5.89	3.98	1.90	3.98	0.099
	16946.	25785.	13.312	21.86	49.84	10.26	8.06	2.20	8.07	-0.083
	18211.	15888.	8.212	38.08	49.79	16.64	14.03	2.61	14.03	0.020

WT LBS	TORQ CNTS	ROLL CNTS	DELTA T	AVG TORQ	AVG S	MEAS AHP	MEAS IHP	CALC FHP	CALC IHP	% DEV
2500.	15795.	48602.	25.095	10.81	49.84	6.05	3.99	2.06	3.98	0.234
	18509.	28396.	14.670	21.66	49.81	10.35	7.99	2.36	8.00	-0.196
	20058.	17567.	9.082	37.92	49.78	16.72	13.97	2.75	13.96	0.045
2750.	17460.	53417.	27.544	10.88	49.91	6.06	4.02	2.04	4.02	-0.004
	20514.	31445.	16.228	21.71	49.86	10.29	8.01	2.28	8.01	0.003
	22183.	19401.	10.013	38.04	49.86	16.68	14.04	2.64	14.04	-0.001
3000.	18633.	57250.	29.543	10.83	49.87	6.17	4.00	2.17	4.00	-0.080
	22171.	33875.	17.488	21.77	49.85	10.42	8.03	2.39	8.02	0.065
	24081.	21062.	10.877	38.01	49.83	16.75	14.02	2.73	14.02	-0.015
3500.	20682.	63580.	32.821	10.82	49.85	6.48	3.99	2.48	3.99	-0.078
	25209.	38453.	19.869	21.79	49.80	10.70	8.03	2.67	8.02	0.066
	27726.	24249.	12.531	37.99	49.80	16.96	14.00	2.96	14.00	-0.015
4000.	24802.	76459.	39.439	10.80	49.89	6.16	3.99	2.17	3.99	-0.095
	29745.	45335.	23.403	21.82	49.85	10.38	8.05	2.33	8.04	0.080
	32389.	28412.	14.676	37.89	49.82	16.55	13.97	2.58	13.97	-0.019
4500.	26847.	82028.	42.343	10.89	49.85	6.45	4.02	2.44	4.01	0.036
	32585.	49824.	25.724	21.75	49.84	10.62	8.02	2.60	8.02	-0.029
	35926.	31347.	16.199	38.08	49.80	16.87	14.03	2.84	14.03	0.007
5000.	28789.	87771.	45.281	10.92	49.88	6.71	4.03	2.68	4.02	0.233
	35512.	54165.	27.951	21.82	49.87	10.86	8.05	2.81	8.07	-0.195
	39583.	34660.	17.888	38.00	49.86	16.98	14.02	2.96	14.01	0.045
5500.	30232.	92539.	47.718	10.88	49.90	7.00	4.02	2.98	4.02	-0.081
	38040.	58022.	29.953	21.81	49.85	11.15	8.04	3.11	8.04	0.067
	42700.	37159.	19.188	38.21	49.83	17.41	14.09	3.32	14.09	-0.015

VEHICLE INERTIA SETTING LBS	WITHOUT A/C VALUES		WITH A/C VALUES		GENERAL EQUATION IND. = M*ACT. + B		REGRESSION COEFFICIENT	FRICTIONAL HP DATA		
	ACT HP.	IND HP.	ACT HP.	IND HP.	- M -	- B -		FHP	DIF FROM PREVIOUS CALIB	DIFF AS % OF AHP
1750.	7.70	5.85	8.50	6.58	0.9093	-1.1514	1.00000	1.85	0.0	0.0
2000.	8.30	6.29	9.10	7.03	0.9223	-1.3673	1.00000	2.01	0.0	0.0
2250.	8.80	6.70	9.70	7.54	0.9344	-1.5227	1.00000	2.10	0.0	0.0
2500.	9.40	7.11	10.30	7.95	0.9360	-1.6868	1.00000	2.29	0.0	0.0
2750.	9.90	7.64	10.90	8.58	0.9435	-1.7009	1.00000	2.26	[illegible]0	0.0
3000.	10.30	7.91	11.30	8.86	0.9468	-1.8393	1.00000	2.39	0.0	0.0
3500.	11.20	8.50	12.30	9.55	0.9543	-2.1860	1.00000	2.70	0.0	0.0
4000.	12.00	9.60	13.20	10.75	0.9605	-1.9260	1.00000	2.40	0.0	0.0
4500.	12.70	10.02	14.00	11.27	0.9616	-2.1919	1.00000	2.68	0.0	0.0
5000.	13.40	10.53	14.70	11.80	0.9730	-2.5051	1.00000	2.87	0.0	0.0
5500.	13.90	10.70	15.30	12.05	0.9678	-2.7537	1.00000	3.20	0.0	0.0
5500.+	14.4	11.2	15.8	12.5	0.9678	-2.7537				

SUMMARY OF FRICTIONAL HORSEPOWER DATA FOR D001 - 4/26/77

PROCESSED: JUL 25, 1977 08:05:58

I.W.	AVERAGE FHP N	AVERAGE FHP AVG	AVERAGE FHP SIGMA	AVERAGE FHP %CV	CORRECTED AVERAGE FHP N	CORRECTED AVERAGE FHP AVG	CORRECTED AVERAGE FHP SIGMA	CORRECTED AVERAGE FHP %CV	FEDERAL REGISTER FHP N	FEDERAL REGISTER FHP AVG	FEDERAL REGISTER FHP SIGMA	FEDERAL REGISTER FHP %CV	INTERCEPT FHP N	INTERCEPT FHP AVG	INTERCEPT FHP SIGMA	INTERCEPT FHP %CV
2000(1)	4	0.565	0.037	6.54	4	0.565	0.037	6.54	4	0.572	0.033	5.77	4	0.574	0.067	11.66
1000	5	0.514	0.033	6.52	5	0.514	0.033	6.52	5	0.517	0.033	6.46	5	0.532	0.045	8.45
500	5	0.325	0.020	6.30	5	0.325	0.020	6.30	5	0.333	0.021	6.31	5	0.310	0.052	16.82
250	3	0.188	0.034	17.97	3	0.188	0.034	17.97	3	0.188	0.031	16.69	3	0.173	0.039	22.83
TRIM	1	1.205	0.0	0.0	1	1.205	0.0	0.0	1	1.192	0.0	0.0	1	1.151	0.0	0.0

DYNAMOMETER CALIBRATION TABLE: 4-26-77

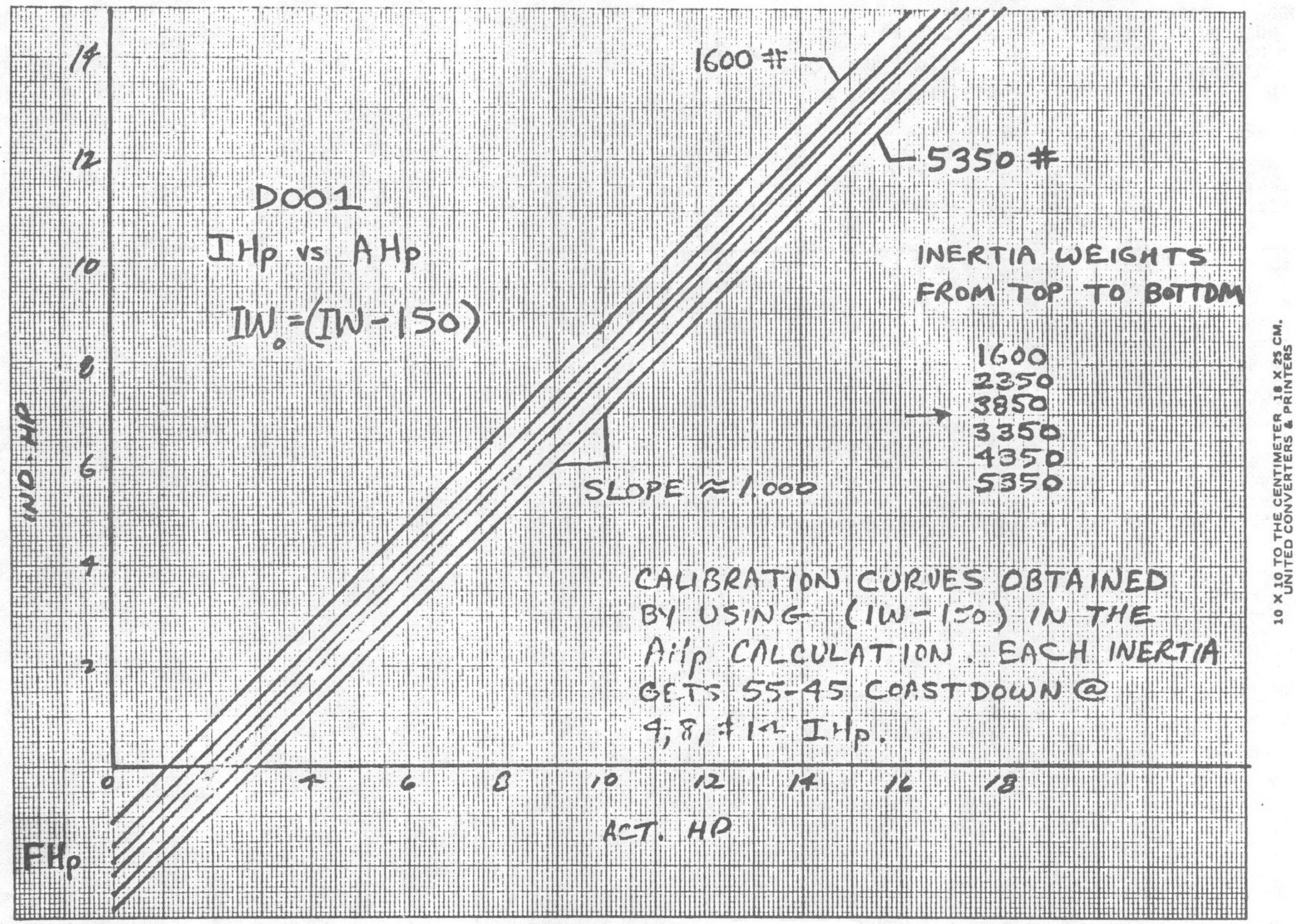
```
DDDDDD      000000    000000    11111
 DD  DD   00     00  00     00  11  11
 DD   DD  0       0  0       0      11
 DD  DD   00     00  00     00      11
DDDDDD      000000    000000   11111111
```

VEHICLE INERTIA SETTING LBS	WITHOUT A/C VALUES ACT HP.	WITHOUT A/C VALUES IND HP.	WITH A/C VALUES ACT HP.	WITH A/C VALUES IND HP.	GENERAL EQUATION IND. = M*ACT. + B - M -	GENERAL EQUATION - B -
1750.	7.7	5.9	8.5	6.6	0.9093	-1.1514
2000.	8.3	6.3	9.1	7.0	0.9223	-1.3673
2250.	8.8	6.7	9.7	7.5	0.9344	-1.5227
2500.	9.4	7.1	10.3	8.0	0.9360	-1.6868
2750.	9.9	7.6	10.9	8.6	0.9435	-1.7009
3000.	10.3	7.9	11.3	8.9	0.9468	-1.8393
3500.	11.2	8.5	12.3	9.6	0.9543	-2.1860
4000.	12.0	9.6	13.2	10.8	0.9605	-1.9260
4500.	12.7	10.0	14.0	11.3	0.9616	-2.1919
5000.	13.4	10.5	14.7	11.8	0.9730	-2.5051
5500.	13.9	10.7	15.3	12.1	0.9678	-2.7537
5500.+	14.4	11.2	15.8	12.5	0.9678	-2.7537

NOTE: 5500.+ SETTING IS FOR INERTIA WTS. ABOVE 5751 LBS.

SET THE SPECIFIED INERTIA WEIGHT. CHECK THE (ACT HP.) REQUESTED ON THE TEST DATA SHEET. LOCATE THIS NUMBER IN THE (W/O A/C) OR (WITH A/C) COLUMN. SET THE ADJACENT VALUE (IND HP. @ 50 MPH) ON THE DYNO HP. METER RECORD THIS VALUE ON THE DRIVER'S TRACE.

NOTE: IF THE REQUESTED VALUE DOES NOT AGREE WITH EITHER COLUMN, VERIFY THE VALUE WITH THE REQUESTOR AND USE THE GENERAL EQUATION TO CALCULATE THE (IND HP.) REQUIRED.



D001
IHp vs AHp
IW₀=(IW-150)
1600 #
5350 #
INERTIA WEIGHTS FROM TOP TO BOTTOM
1600
2350
3850
3350
4350
5350
SLOPE ≈ 1.000
CALIBRATION CURVES OBTAINED BY USING (IW-150) IN THE AHp CALCULATION. EACH INERTIA GETS 55-45 COASTDOWN @ 4, 8, & 12 IHp.
IND. HP
ACT. HP
FHp
14
12
10
8
6
4
2
0
4
6
8
10
12
14
16
18
10 X 10 TO THE CENTIMETER 18 X 25 CM.
UNITED CONVERTERS & PRINTERS

FRICTIONAL Hp

TOTAL INERTIA	IW (-150)	D001	D002	D003	D004	D005	D006
1750	1600	1.19	1.32	1.10	1.36	1.19	1.06
2000	1850	1.39	1.60	1.28	1.54	1.41	1.19
2250	2100	1.51	1.64	1.38	1.68	1.41	1.32
2500	2350	1.73	1.87	1.55	1.84	1.61	1.42
2750	2600	1.72	1.80	1.52	1.81	1.59	1.49
3000	2850	1.87	2.03	1.65	1.99	1.79	1.59
3500	3350	2.22	2.34	1.83	2.30	2.01	1.79
4000	3850	1.95	2.23	1.88	1.99	2.00	1.63
4500	4350	2.26	2.52	2.01	2.28	2.23	1.86
5000	4850	2.46	2.68	2.27	2.46	2.41	2.09
5500	5350	2.82	2.94	2.55	2.81	2.64	2.31
	REAR ROLL FHP	.145	.160	.146	.083	.167	.128
	EXP.	2.943	2.956	3.058	3.170	3.087	3.081

FHp = [AHp − IHp] @ FR VALUES.

FHp FOR EPA CERTIFICATION DYNO SITES − ECE 50

CALIBRATED IN AUTO MODE. DATA FOR AHp DOES NOT INCLUDE RR INERTIA.

AVG. = .138 Hp

AVG. = 3.05

MULTIPLE FHp VALUES BASED ON FLYWHEEL ENGAGEMENT

FHp ΔIW WHEEL	DYNO NUMBER D001	D002	D003	D004	D005	D006	AVG. ALL
2000							
5500 - 3500	0.60	0.60	0.72	0.51	0.63	0.52	0.60
5000 - 3000	0.59	0.65	0.62	0.47	0.65	0.50	0.58
4500 - 2500	0.53	0.65	0.46	0.44	0.62	0.44	0.52
4000 - 2000	0.56	0.63	0.60	0.45	0.59	0.44	0.55
AVG FHP	0.57	0.63	0.60	0.47	0.62	0.48	0.56
1000							
5500 - 4500	0.56	0.42	0.54	0.53	0.41	0.45	0.49
5000 - 4000	0.51	0.45	0.39	0.47	0.44	0.46	0.45
3500 - 2500	0.49	0.47	0.28	0.46	0.40	0.37	0.41
3000 - 2000	0.48	0.43	0.37	0.45	0.38	0.40	0.42
2750 - 1750	0.53	0.48	0.42	0.45	0.40	0.43	0.45
AVG FHP	0.51	0.45	0.40	0.47	0.41	0.42	0.44
500							
5500 - 5000	0.36	0.26	0.28	0.35	0.20	0.22	0.28
4500 - 4000	0.31	0.29	0.13	0.29	0.23	0.23	0.25
3500 - 3000	0.35	0.31	0.18	0.31	0.22	0.20	0.26
2500 - 2000	0.34	0.27	0.27	0.30	0.20	0.23	0.27
2250 - 1750	0.32	0.32	0.28	0.32	0.25	0.26	0.29
AVG FHP	0.34	0.29	0.23	0.31	0.22	0.23	0.27
250							
3000 - 2750	0.15	0.23	0.13	0.18	0.20	0.10	0.17
2500 - 2250	0.22	0.23	0.17	0.16	0.17	0.10	0.18
2000 - 1750	0.20	0.28	0.18	0.18	0.22	0.13	0.20
AVG FHP	0.19	0.25	0.16	0.17	0.20	0.11	0.18
TRIM FHP	1.19	1.32	1.10	1.36	1.19	1.06	1.20

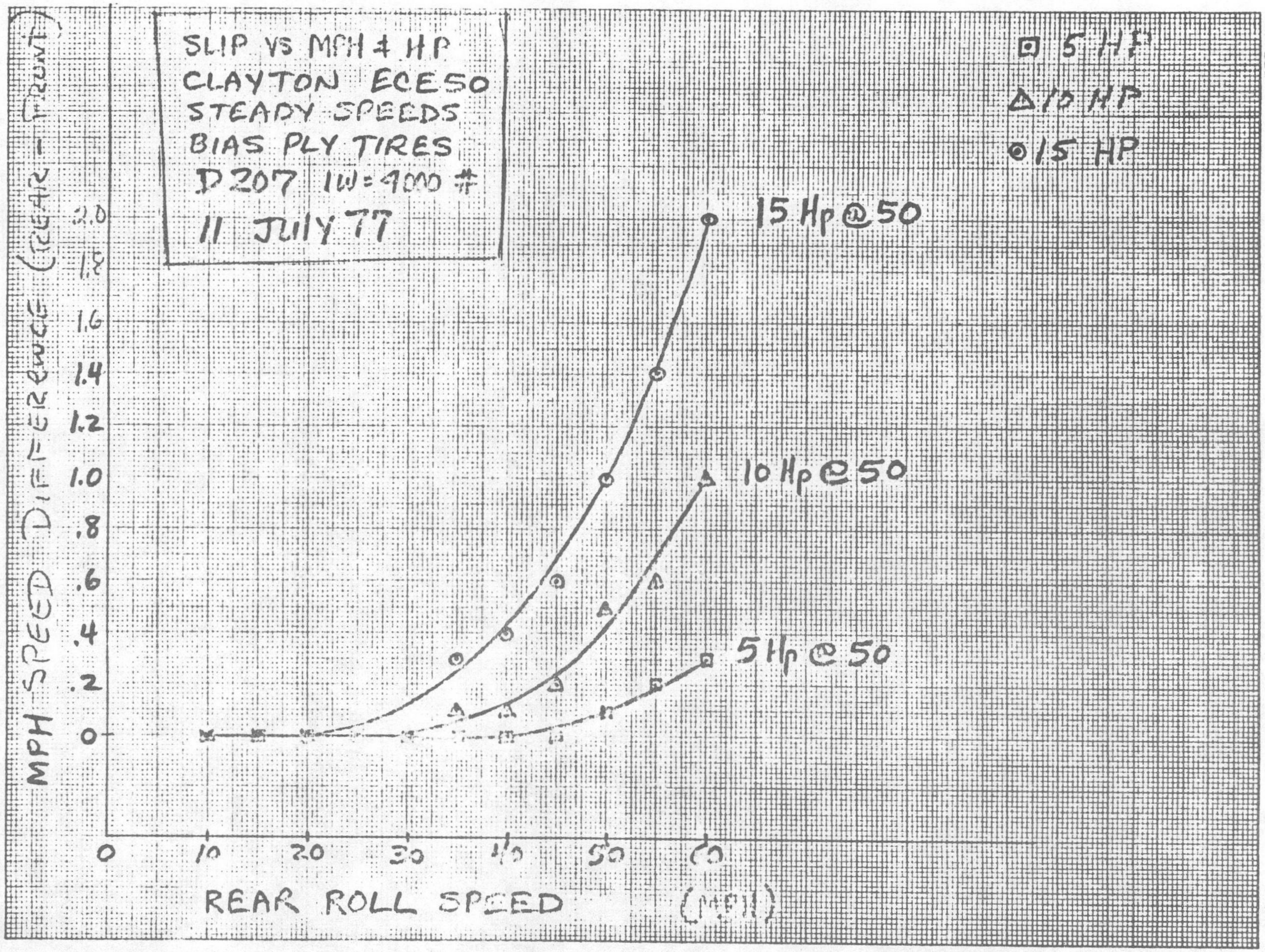
BEST ESTIMATE FOR TRIM (1750) FHP

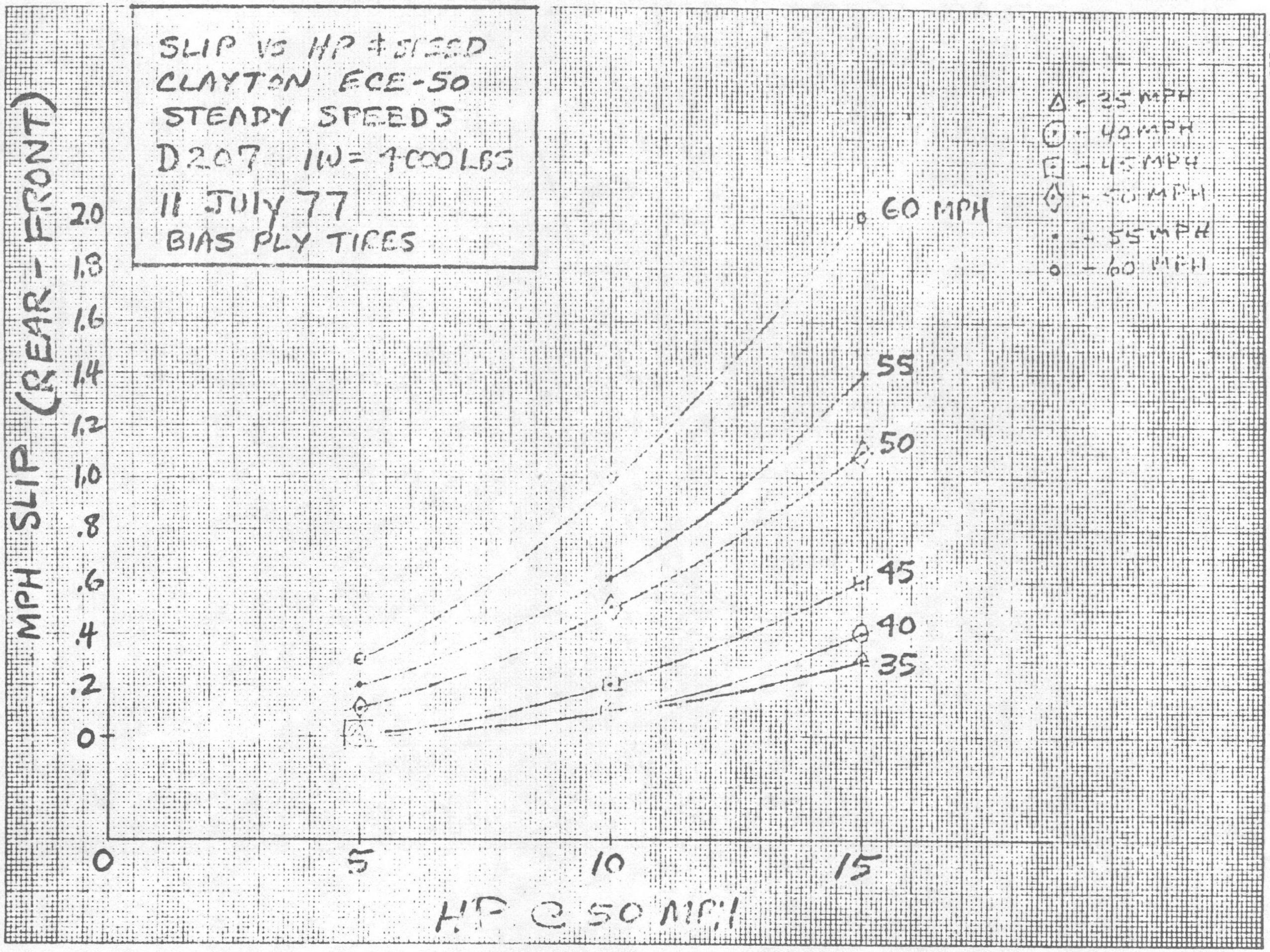
TOTAL I.W.	250	500	1000	2000	DYNO NUMBER D001	D002	D003	D004	D005	D006
5500	X	X	X	X	1.21	1.32	1.16	1.39	1.19	1.07
5000	X		X	X	1.19	1.35	1.11	1.35	1.21	1.08
4500	X	X		X	1.16	1.35	1.02	1.33	1.19	1.04
4000	X			X	1.19	1.35	1.12	1.35	1.18	1.04
3500	X	X	X		1.18	1.35	1.04	1.35	1.18	1.03
3000	X		X		1.17	1.33	1.09	1.35	1.18	1.06
2750			X		1.21	1.35	1.12	1.34	1.18	1.07
2500	X	X			1.20	1.33	1.16	1.36	1.19	1.08
2250		X			1.17	1.35	1.15	1.37	1.22	1.09
2000	X				1.20	1.35	1.12	1.37	1.21	1.08
1750					1.19	1.32	1.10	1.36	1.19	1.06
	AVG. FHP				1.188	1.343	1.109	1.356	1.193	1.064
				σ	.0166	.0116	0.0475	.0171	0.0149	0.0207
				%CV	1.40	.863	4.28	1.26	1.25	1.94
				%Δ	-.168	1.712	.812	-.295	.251	.376

ESTIMATED BEARING FHP

INERTIA	1750 TRIM	250	500	1000	2000
TOTAL FHP	1.20	1.38	1.65	2.09	2.65
# BEARINGS	10	13	16	19	22
FHP/BEARING	.120	.106	.103	.110	.120

AVERAGE FHP/BEARING ≈ .110


SLIP VS MPH & HP
CLAYTON ECE50
STEADY SPEEDS
BIAS PLY TIRES
D207 IW=4000 #
11 JULY 77
5 HP
10 HP
15 HP
15 Hp @ 50
10 Hp @ 50
5 Hp @ 50
MPH SPEED DIFFERENCE (REAR - FRONT)
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
0
10
20
30
40
50
60
REAR ROLL SPEED
(MPH)


SLIP VS HP & SPEED
CLAYTON ECE-50
STEADY SPEEDS
D207 IW = 4000 LBS
11 JULY 77
BIAS PLY TIRES
MPH SLIP (REAR - FRONT)
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
5
10
15
HP @ 50 MPH
60 MPH
55
50
45
40
35
- 35 MPH
- 40 MPH
- 45 MPH
- 50 MPH
- 55 MPH
- 60 MPH

DAIMLER-BENZ

SUBMISSION NO.2 TO EPA

"Investigations about influencing parameters on chassis dynamometer road load adjustment."

6-27-1977
V1MA bg

Table of Contents

1. Introduction

Following our submission no. 1, dated February 27, 1977, Daimler-Benz, herewith, provides information about further investigations on the subject of road load determination and the corresponding chassis dynamometer adjustment.

With increasing knowledge on parameters, effecting power determination, power dissipative losses and power simulation on twin roll dynos, need for in depth studies seemed imperative.

In this respect, tires turned out to be one of the most important, yet critical and complex part of the system.

For these reasons, the target of determining the influence of different chassis dynamometer adjustments on exhaust emissions and fuel economy was postponed until

- the necessary basic knowledge of the surrounding problems was considered to be sufficient
- the complete DB model mix was reliably measured for exact road load determination

2. Daimler-Benz's Chassis Dynamometer Description

Today, Daimler-Benz operates the following dynamometers:

Total no. of Dynos	Dyno Type	Power Range	Inertia Range
3	Schenck Water Brake direct drive	0 - 180 HP	1500 - 5000 lbs. 500 lbs. increments and 250 lbs. increments (1 dyno)
2	Schenck Eddy Current Brake direct drive	0 - 60 HP	1750 - 5625 lbs. 125 lbs. increments
3	Schenck Water Brake direct drive	0 - 180 HP	1750 - 5500 lbs. 250 lbs. increments
1	Schenck Water Brake direct drive	0 - 180 HP	1500 - 5375 lbs. 125 lbs. increments.

For certification purposes, DB will install additionally:

3	Clayton ECE-50 Water Brake with RLPC direct drive	0 - 50 HP	1750 - 5500 lbs. 125 lbs. increments roll dia. 8.65 in. roll space 17.25 in.

For research and development work, DB intends to order:

1	Schenck DC with fly-wheels	0 - 75 HP	1500 - 10 000 lbs. 125 lbs. increments

The Schenck dynos have a roll diameter of: 14.3 in. (364 mm)
and a roll spacing of: 21.65 in. (550 mm).

3. Parameters under Investigation

3.1 Restraint Force

During exhaust emission testing on chassis dynamometers, the vehicle is normally secured by means of safety cables, winches etc. hooked to the bumper or any other adequate point of the vehicle, in order to avoid rocking of the car.

By avoiding rocking of the vehicle, additional rolling resistance might be caused depending on the force with which the drive wheels are pressed to the free running rear roll of the dynamometer. This fact can void the assumption that driving on a twin roll simulates automatically front wheel rolling resistance.

For investigation purposes, the restraint forces were divided into three steps according to the notches of the winch (the winch was purchased in the US and is of the same configuration as used in EPA's laboratory Ann Arbor):

Position	Restraint Force (kp)	(N)
0	0	(0)
1st notch	150	(1472)
2nd notch	300	(2943)

The angle between the horizontal plane and the cable was ≈ 12 degrees, and the vertical component of the restraint force (causing increased rear axle loading) was neglected in this evaluation.

Diagram A shows the rolling resistance increase (total torque increase) depending on the restraint force for a given vehicle weight/tire combination.

In position 0 (safety cable "loose"), the vehicle can climb up onto the front roll, thereby reducing flexing resistance on the rear roll. In position 1 and 2, the tire is pressed more and more to the rear roll increasing rolling resistance (measured as torque) from 16.2 mkp (117.2 ft.lb.) to 18 mkp (130.2 ft.lb.) at the adjustment point of 80 km/h (50 mph).

3.2 Rear Axle Load

A Daimler-Benz vehicle code A was positioned on the chassis dynamometer and lifted stepwise from the rolls in order to achieve different rear axle loadings.
A force measurement device was installed between lift hook and vehicle.
The original rear axle load of 984 kp (9653 N) was reduced in steps of 100 kp (981 N) until a rear axle load of 480 kp (4709 N) was reached.

Diagram B shows the effect of rear axle load on the rolling resistance for the given weight/tire combination for two different vehicle speeds: 40 and 80 km/h (25 and 50 mph) measured as torque.

An extrapolation of the curves to 0 axle load leads to the resistance necessary to overcome the dynamometer's HP setting (including dissipative losses of drive train and drive wheels).

A similar measurement, however, with "no load" HP setting and the dynamometer motoring the vehicle would deliver dissipative losses of drive train and drive wheels as outlined in "Light Duty Truck Road Load Determination" by Glenn Thompson (US-EPA), dated September 1976.

3.3 Tire Pressure

It is very difficult to separate the influence of tire pressure and tire temperature on rolling resistance, if no device is used to keep the tire pressure constant at a specified level.

After several trial runs we succeeded, however, in keeping the tire surface temperature almost constant at about 70 °C (158 °F) for these tire pressure comparison tests. (While reaching the 70 °C starting from room temperature, the tire pressure increased from 3.0 bar initial adjustment to 3.8 bar).

At ≈ 70 °C tire surface temperature, the tire pressure was varied from 2.8 to 4.3 bar.

Diagram C shows the decreasing rolling resistance (measured as torque) with increasing tire pressure for vehicle speeds of 40 and 80 km/h (25 and 50 mph).

3.4 Tire Temperature

The fact that tire (surface) temperature varies over a wide range before and during exhaust emission tests and since it is impracticable to control that temperature, only an estimation of its effect on rolling resistance can be given.

Tire temperature depends on

- configuration of dynamometer (roll space, roll diameter)
- speed level for a given time
- tire pressure
- axle load
- number of load changes etc.

To achieve a basis for above investigations, the following steps were performed:

a) dynamometer and vehicle were warmed up,
b) the wheels (tires) were changed against wheels (tires) with room temperature,
c) immediate acceleration to 80 km/h (50 mph), which is then kept constant,
d) recording of torque change until a constant level was reached.

Table 1 shows mainly the effect of increasing tire temperature (additional effects of increased tire pressure could, however, not be fully eliminated).

The tests were made for different tire dimensions; index 1 represents the beginning, index 2 the end of the test (=torque stabilized).

3.5 Tire Dimensions

Different tire dimensions were tested under the same axle load and showed substantial differences in rolling resistance (measured as torque).

This study is of limited practical value, since a given car weight predetermines (or at least narrows the range of) the tires which must be used for this vehicle.
It might, however, influence decision making processes related to vehicle weight and tire selection questions.

The results of the comparison are shown in diagram D.

3.6 Break-Loose Torque on Road and Chassis Dynamometer

Since static measurements (at constant speed steps) are only one portion of exact dynamometer adjustment, Daimler-Benz has in the past and will continue in the future to evaluate means for dynamic comparisons of actual road load conditions with chassis dynamometer behaviour.

One of the many tests made in this respect deal with the different break-loose forces on road and dynamometer.

The engine rpm of the test vehicle was adjusted to 1200 rpm and the brakes applied. Then the transmission was shifted into "D" position. After that, the brakes were released so that the vehicle could accelerate.

Diagram E shows the difference obtained from torque measurements on road and dyno.

Due to the fact that the dynamometer is a "flexible" unit compared to the road, the torque in position "D" differs.

When the brakes are released, the vehicle accelerates immediately on the street, whereas there occurs a certain swinging on the rolls before the car gains speed (due to the play in the dyno system).

The torque peak at the beginning of acceleration was slightly higher (56:60.5 mkp = 405:437.6 ft.lb.) on the dynamometer for this vehicle/tire combination.

4. Actual Road Load for MB Cars

DB's application for the use of torque measurements for MY 1979 certification is not yet complete, since some vehicles still have to be road tested under the necessary good weather conditions.
However, two cars shall be compared in this submission, showing that the difference between Federal Register Table and actual road load varies from car to car. This results in the necessity of carefully measuring each individual car on the road exactly in its sales execution (weight, tires etc.).

Diagram F (vehicle code: A) shows only slight differences between Federal Register Table and actual road load conditions, so that no separate curve for actual road load was plotted.

Diagram G (vehicle code: B) shows, however, a difference which has to be considered when the dynamometer is adjusted.

Since the difference between Federal Register Table and actual road load varies from 0 HP to approx. 3 HP depending on vehicle type, some comparison tests were performed in order to obtain an estimate of the load influence on emissions and fuel economy.

The vehicle (code B) was tested with the following dynamometer load settings:

a) according to Federal Register (4500 lbs. class)
b) Federal Register value minus 2,5 HP.

The influence on emissions and fuel economy during a HWFET was ≈

	NO_x	FE
	-0,2 g/m	+1,0 mpg

This result is, however, based on a limited number of tests (5 tests for each setting) and has to be backed up by more testing in order to achieve the necessary statistical confidence.

5. Comparison of Schenck water brake and Schenck eddy current brake dynamometers.

During Part I (MY 78) revision, DB was asked by EPA to submit comparison curves for its water brake and eddy current brake type dynamometers.

The dynamometers were adjusted to the same HP setting at 80 km/h (50 mph) and constant speeds were run in 20 km/h steps from 20 to 100 km/h (≈12 to ≈ 62 mph).

The characteristics are shown in diagram H.

6. Summary and Conclusions

According to the aforementioned findings, the following can be stated:

a) road load calculation for DB vehicles according to the previously proposed formula (§86.129-79) results in substantially higher power settings for the chassis dynamometer. (This formula, however, has been withdrawn by EPA in the meantime).

b) The presently valid Federal Register Table still results in a too high chassis dynamometer power setting for some of our vehicles.

Daimler-Benz, therefore, intends to use - starting with MY 1979 - HP settings for its dynamometers as derived from actual road load (torque) measurements in the cases under b).

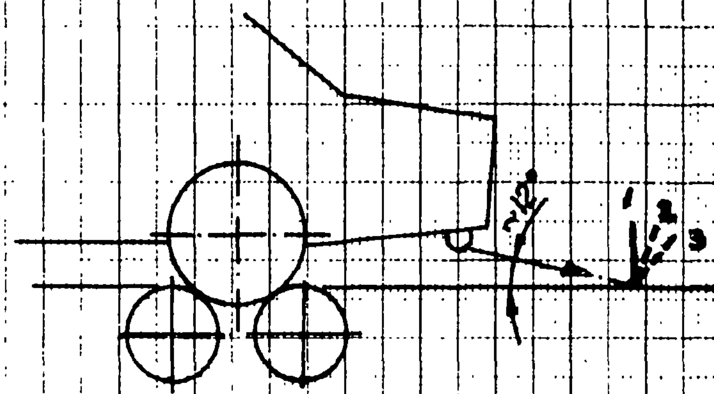
Further investigations will concentrate on establishing exact road load for all DB vehicles, evaluating the dynamic behaviour of different chassis dynamometers, on the adjustability of the chassis dynamometer's load curve exponent and on the influence of all important parameters on exhaust emissions and fuel economy. The corresponding findings will be reported to EPA on the already applied successive basis.

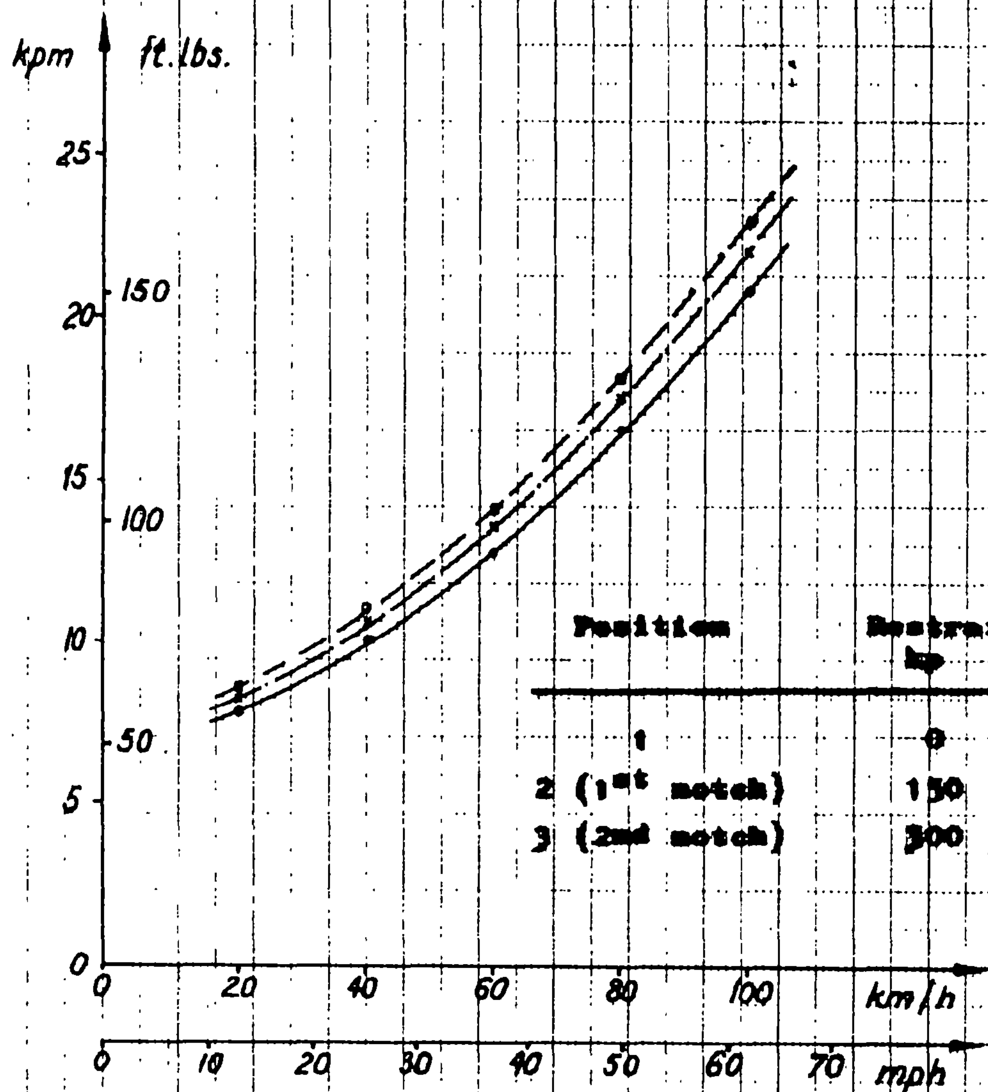
Daimler-Benz AG
Certification Department
V1MA
June 27, 1977

Diagr. A

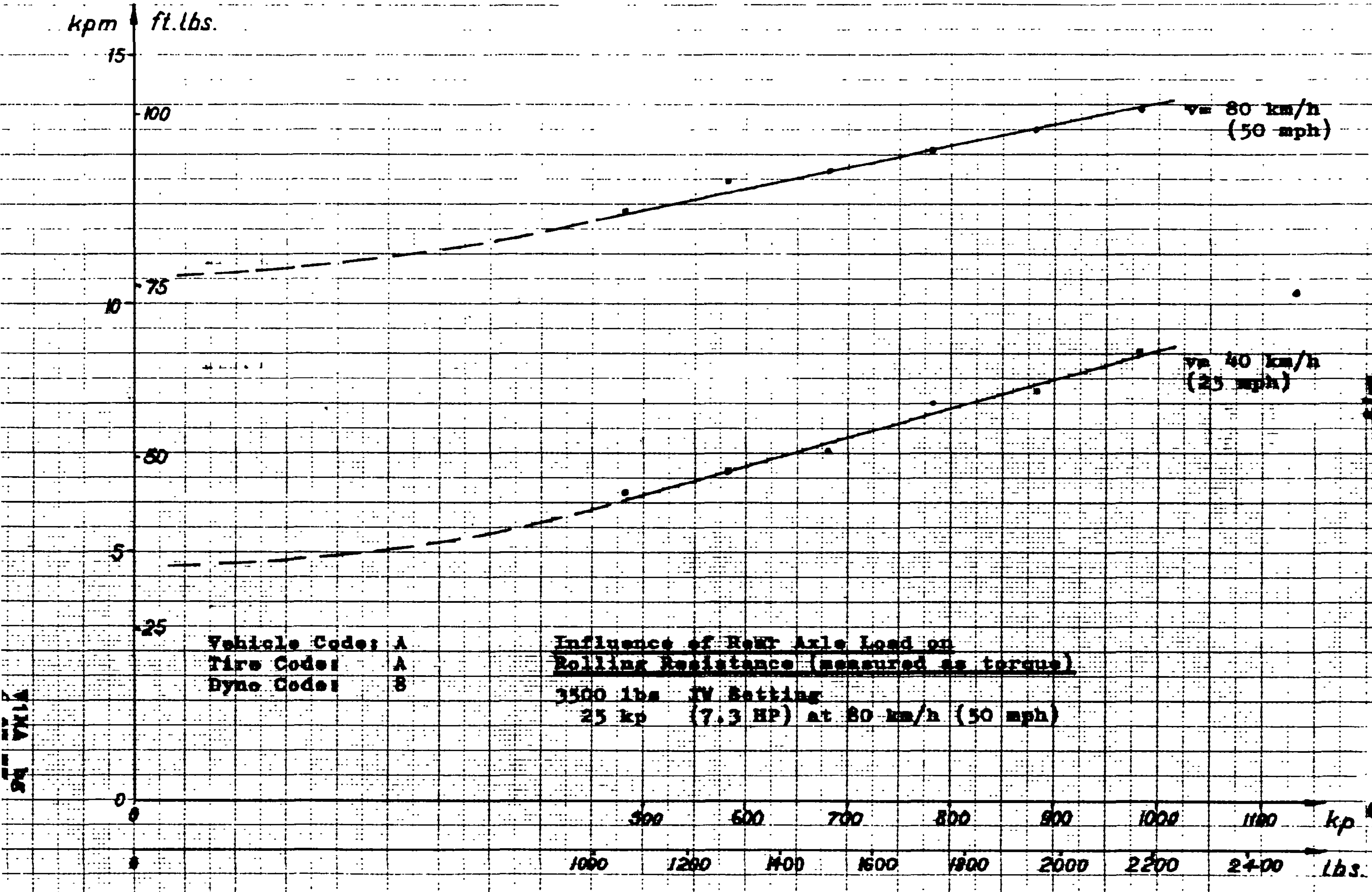
Influence of Restraint Force on Rolling Resistance

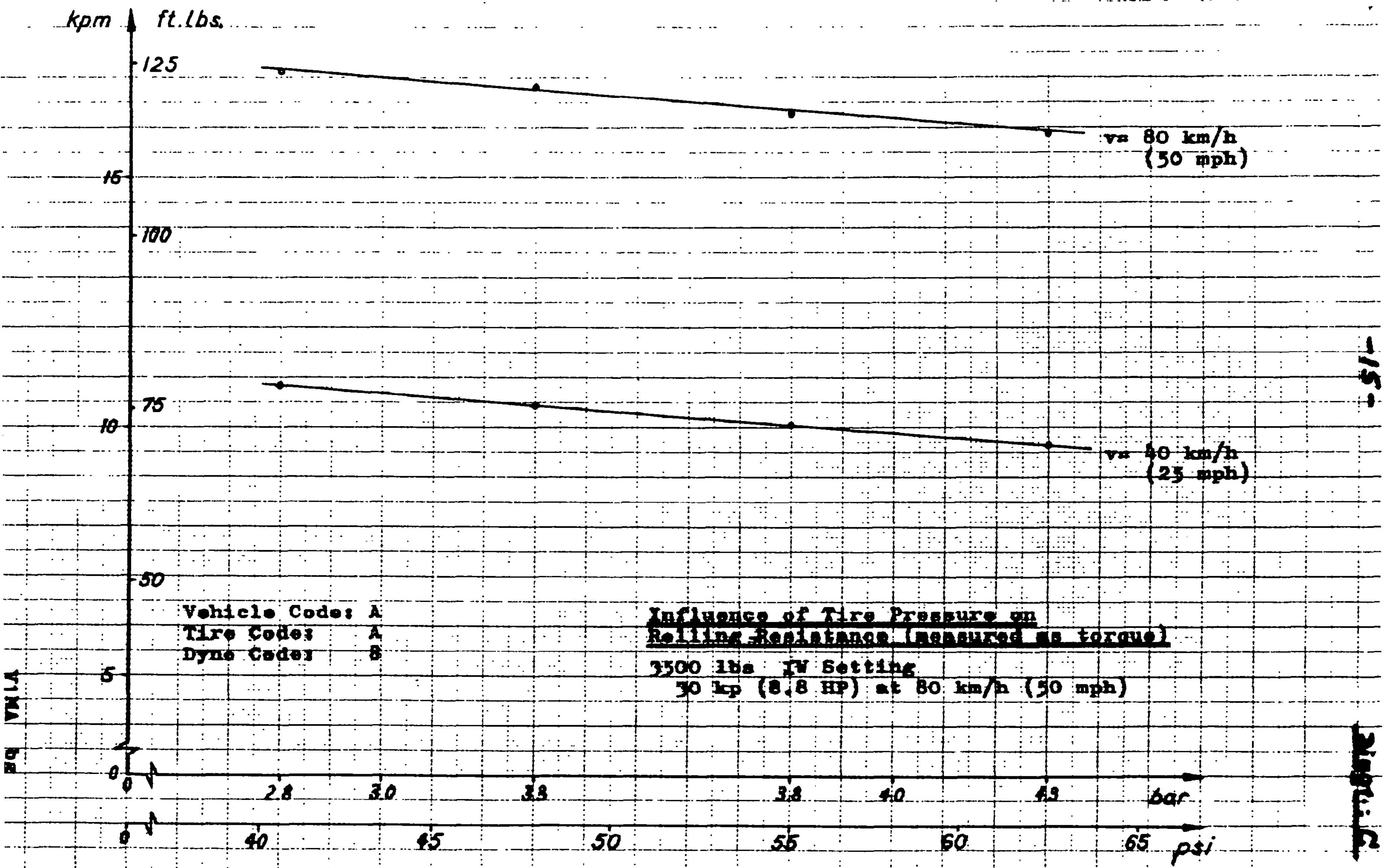
(measured as torque)





Position	Restraint Force kp	N
1	0	0
2 (1st notch)	150	1472
3 (2nd notch)	300	2944


kpm
ft.lbs.
15
100
75
10
50
5
25
0
v= 80 km/h
(50 mph)
v= 40 km/h
(25 mph)
Vehicle Code: A
Tire Code: A
Dyno Code: 8
Influence of Rear Axle Load on
Rolling Resistance (measured as torque)
3500 lbs IW Setting
25 kp (7.3 HP) at 80 km/h (50 mph)
0
500
600
700
800
900
1000
1100
kp
1000
1200
1400
1600
1800
2000
2200
2400
lbs.



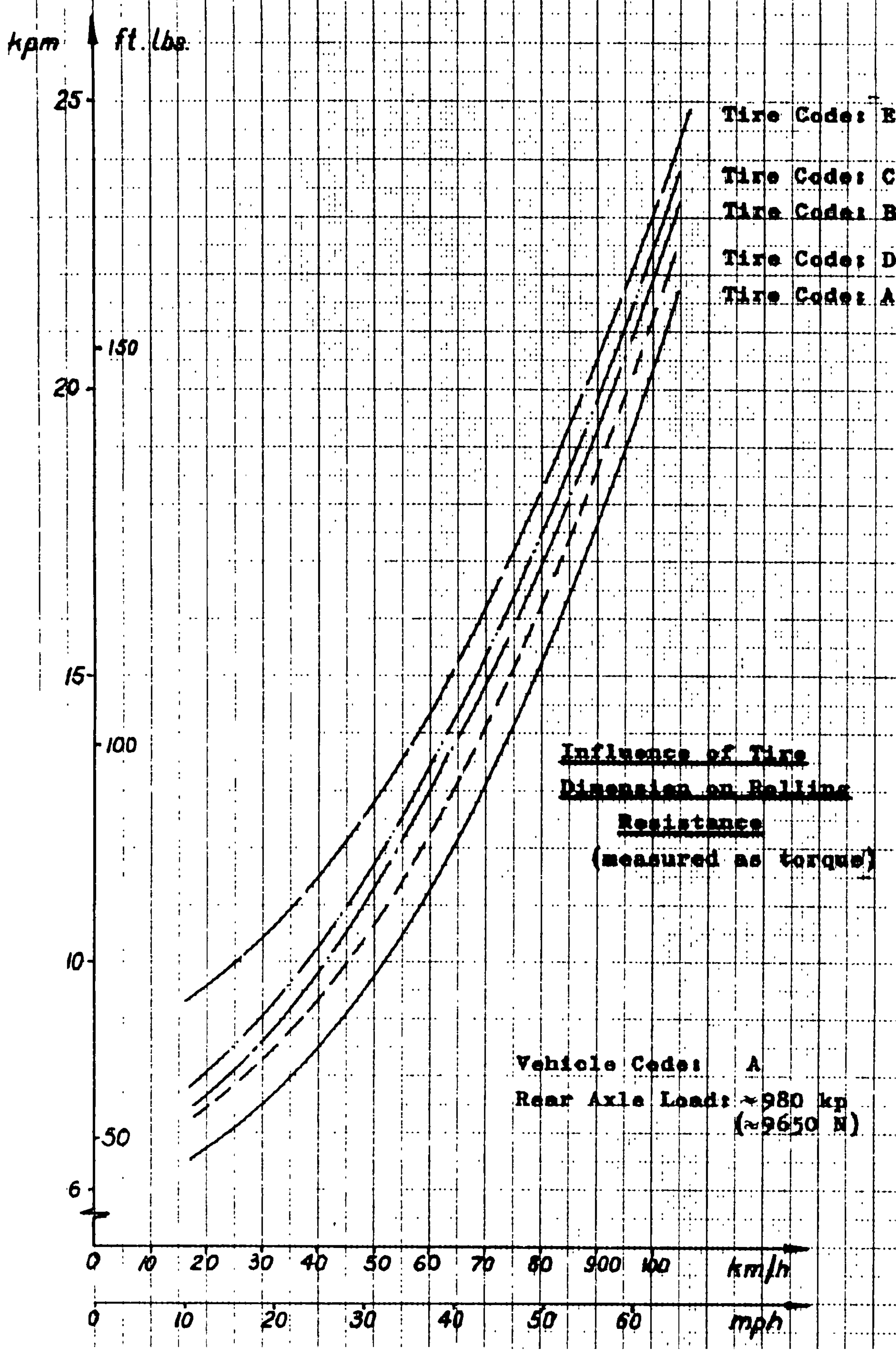
kpm
ft.lbs.
125
15
100
75
10
50
5
0
v= 80 km/h
(50 mph)
v= 40 km/h
(25 mph)
Vehicle Code: A
Tire Code: A
Dyne Code: B
Influence of Tire Pressure on
Rolling Resistance (measured as torque)
3500 lbs IW Setting
30 kp (8.8 HP) at 80 km/h (50 mph)
2.8
3.0
3.3
3.8
4.0
4.3
bar
40
45
50
55
60
65
psi

Table 1

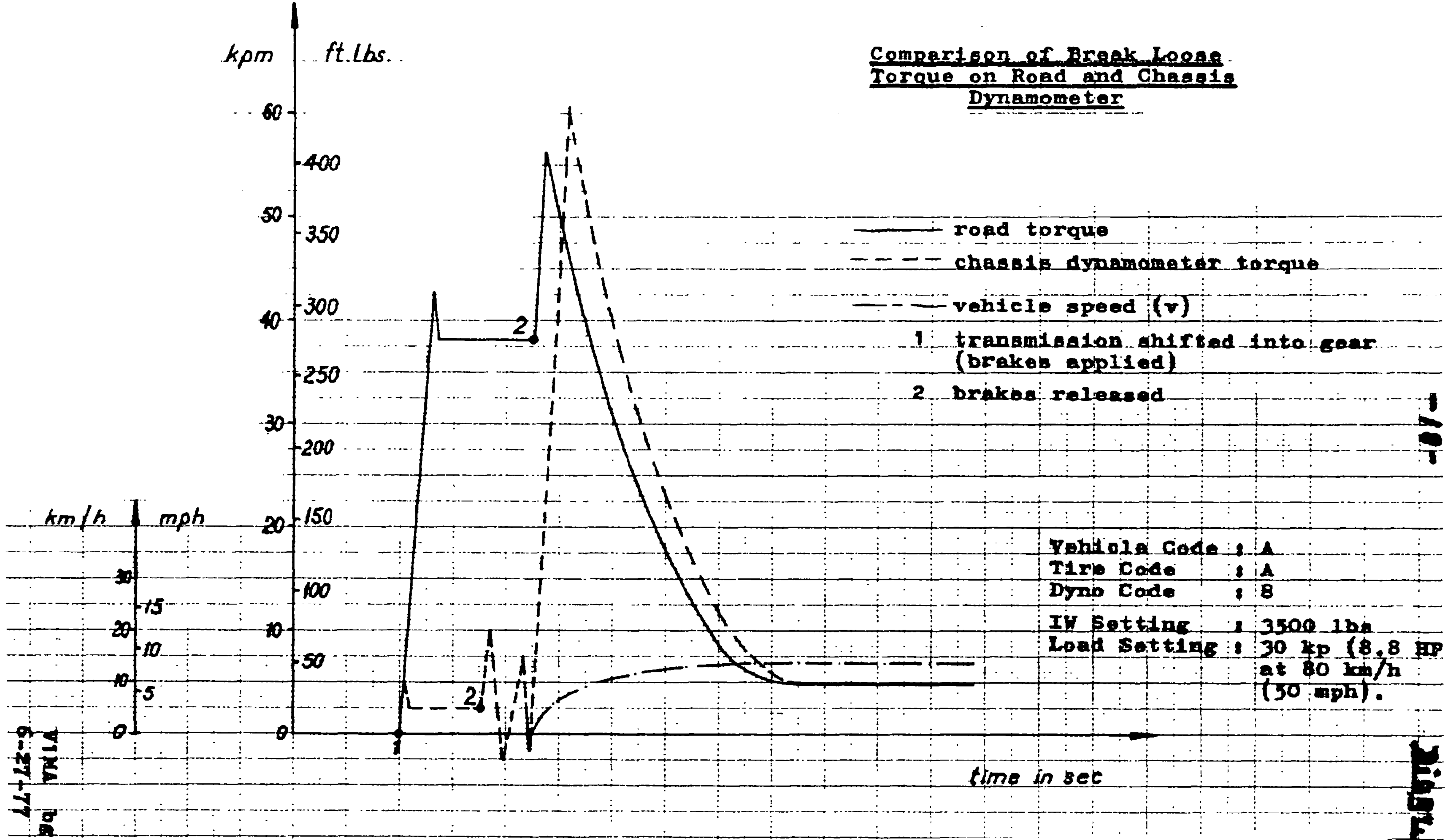
Influence of Tire Temperature on Rolling Resistance

Tire Dimension	Tire Pressure (bar)*)		Tire Temperature (°C)		Tire Temperature (°F)		Torque on Drive Wheels (mkp)		Torque on Drive Wheels (ft.lb.)	
	P_1	P_2	T_1	T_2	T_1	T_2	M_{d1}	M_{d2}	M_{d1}	M_{d2}
175 SR 14	3,2	3,7	23	62	73,4	143,6	16,4	15.0	118.6	108.5
205/70 HR 14	3,2	3,7	23	68	73,4	154,4	18,0	16,8	130.2	121.5
215/70 VR 14	3,2	3,7	23	80	73,4	176	22.4	20.8	162.0	150.4
								stabilized condition		stabilized condition

*) 3,2 bar = 46,4 psi
3,7 bar = 53,6 psi

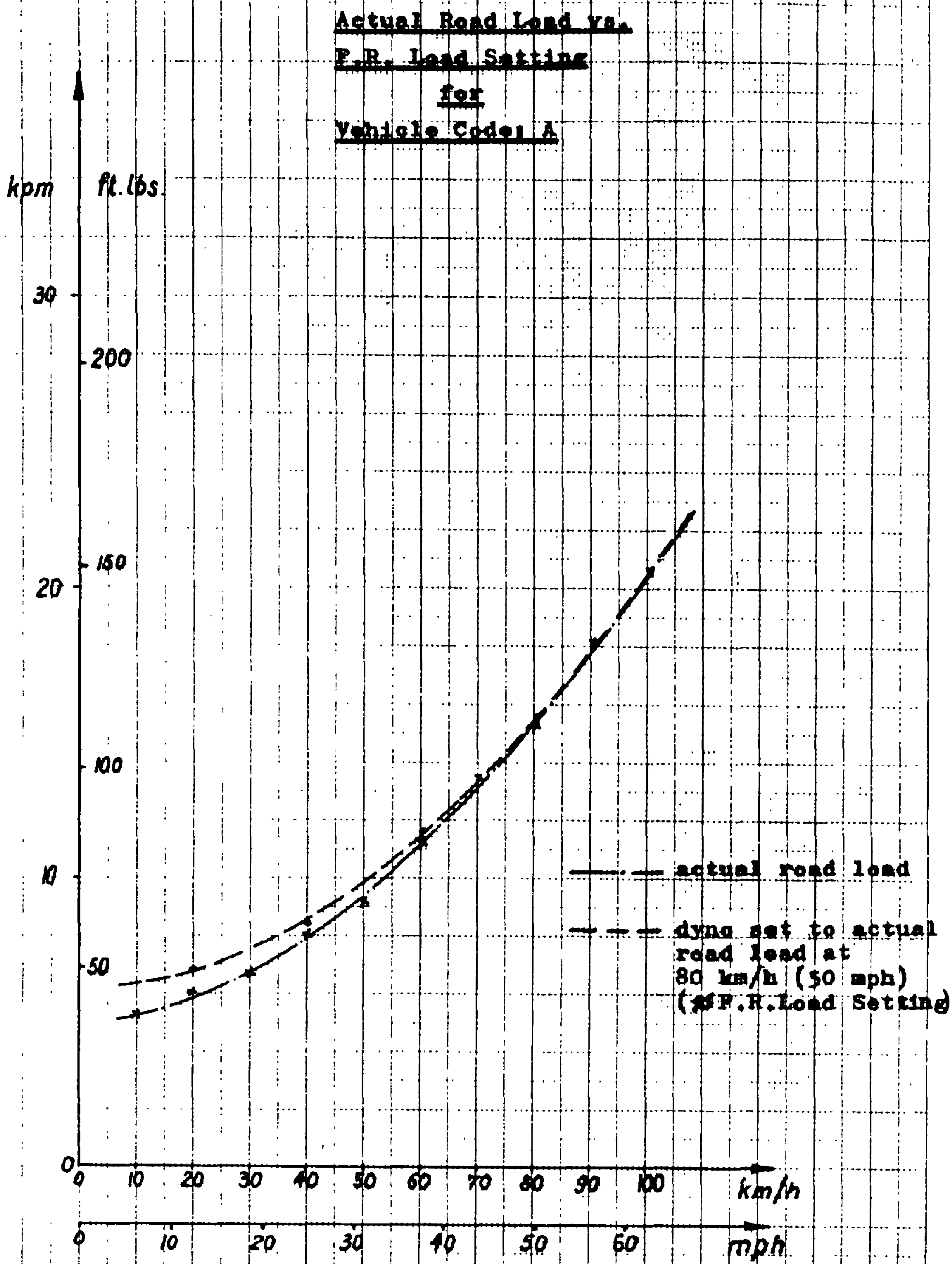

kpm
ft. lbs.
25
20
15
10
6
150
100
50
Tire Code: E
Tire Code: C
Tire Code: B
Tire Code: D
Tire Code: A
Influence of Tire Dimension on Rolling Resistance
(measured as torque)
Vehicle Code: A
Rear Axle Load: ≈ 980 kp
(≈ 9650 N)
0
10
20
30
40
50
60
70
80
90
100
km/h
mph

Comparison of Break Loose Torque on Road and Chassis Dynamometer



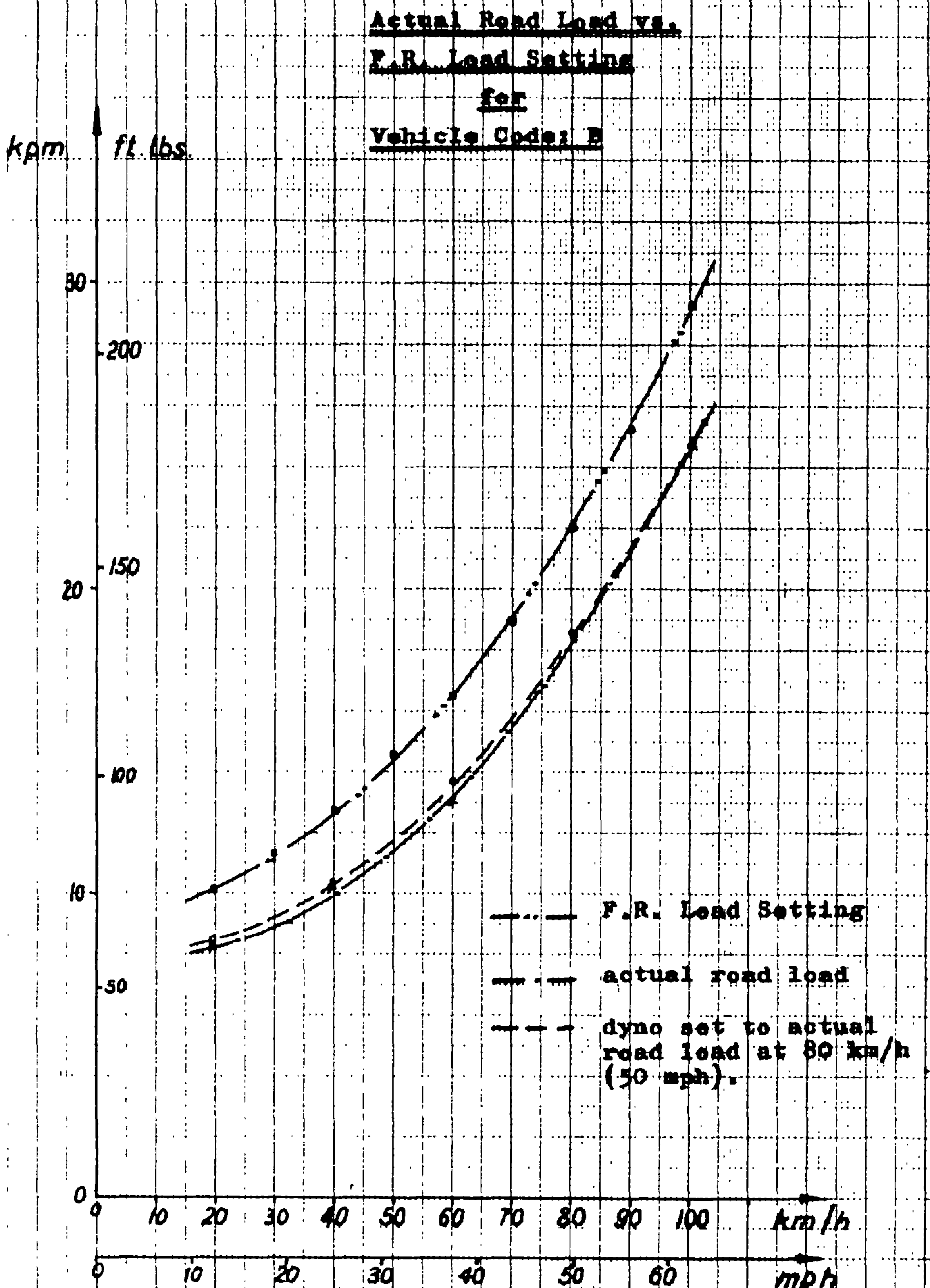
6-27-77 AVL bg

Diagr.: F

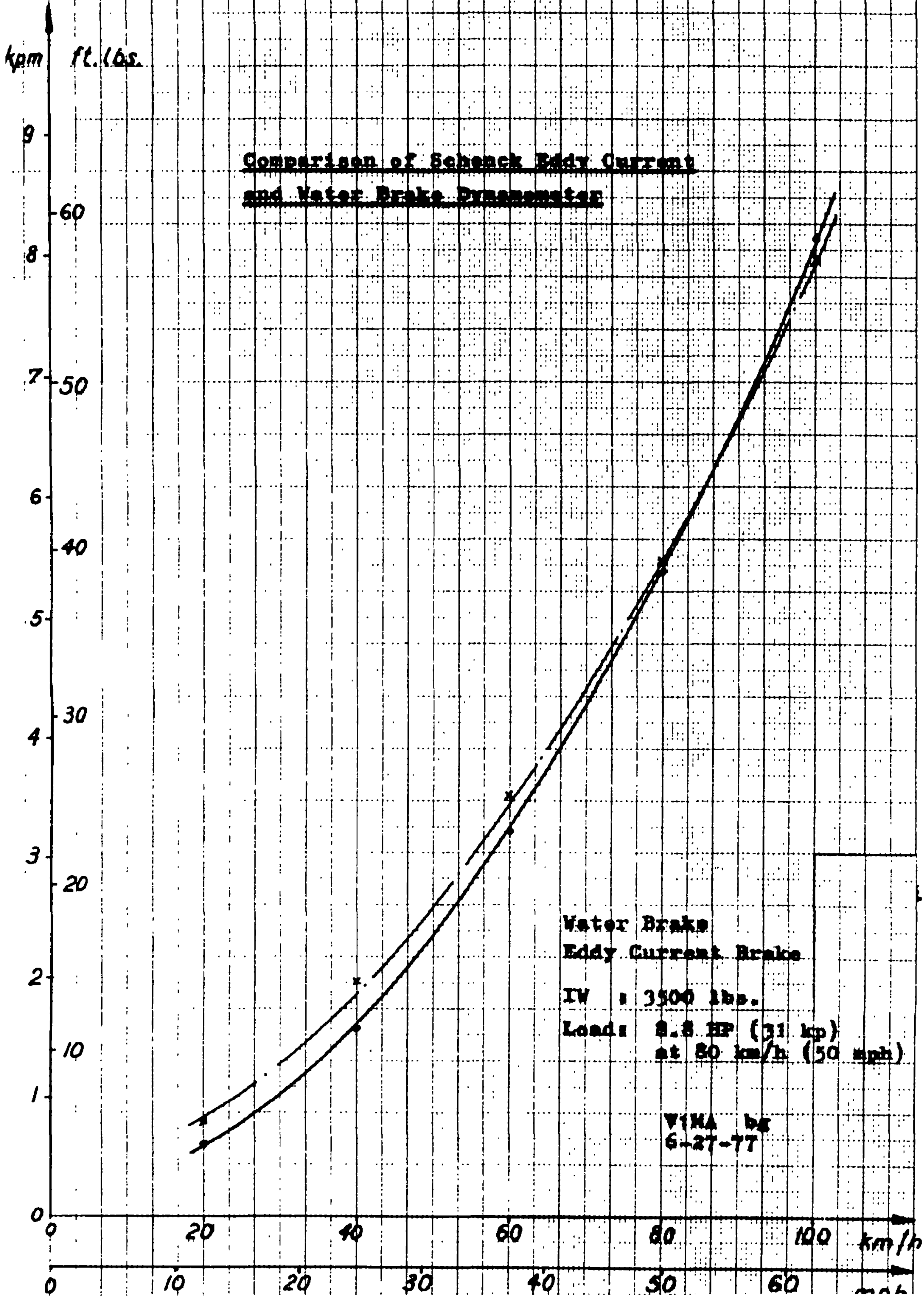


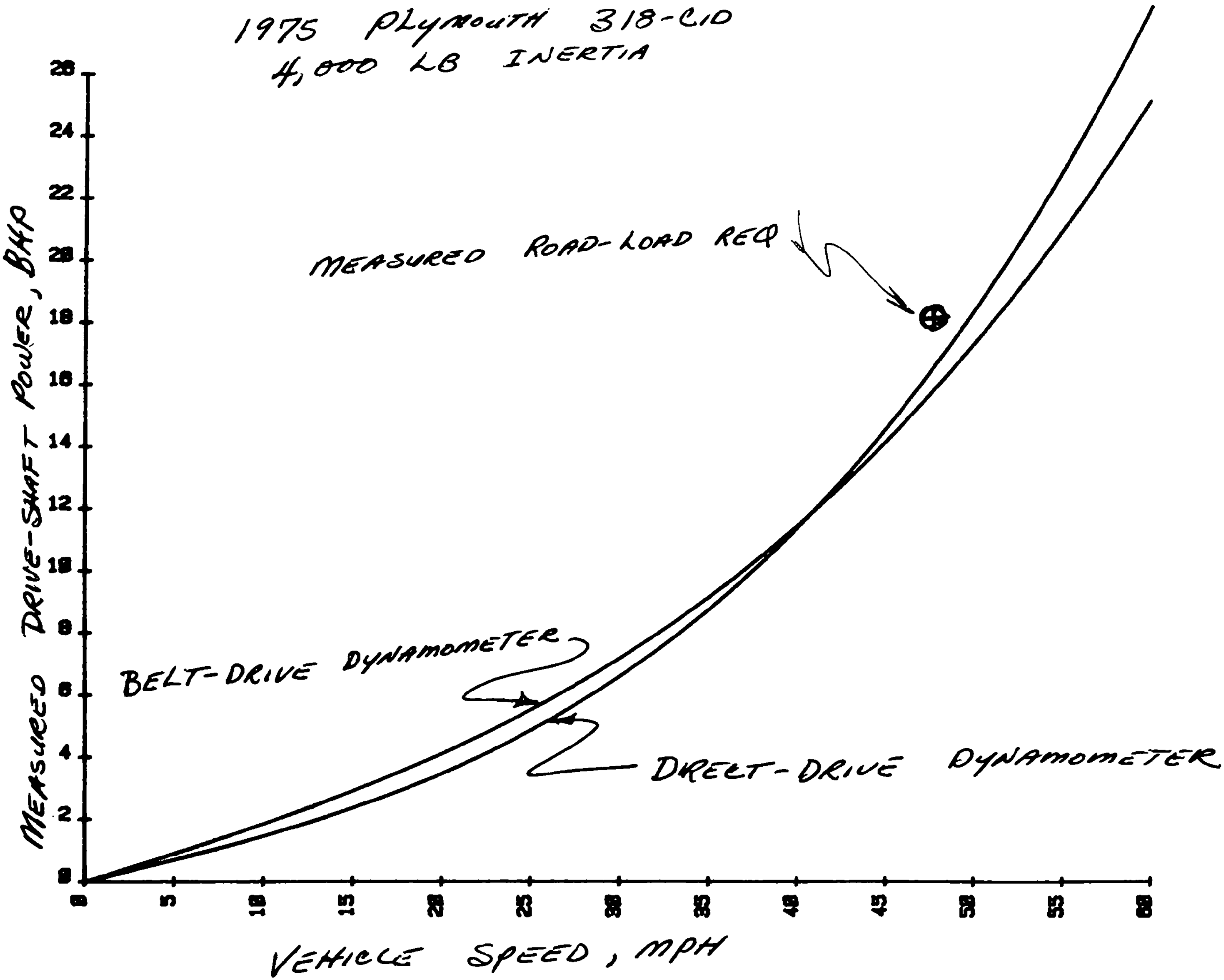
VIMA bg

Diagr.: G



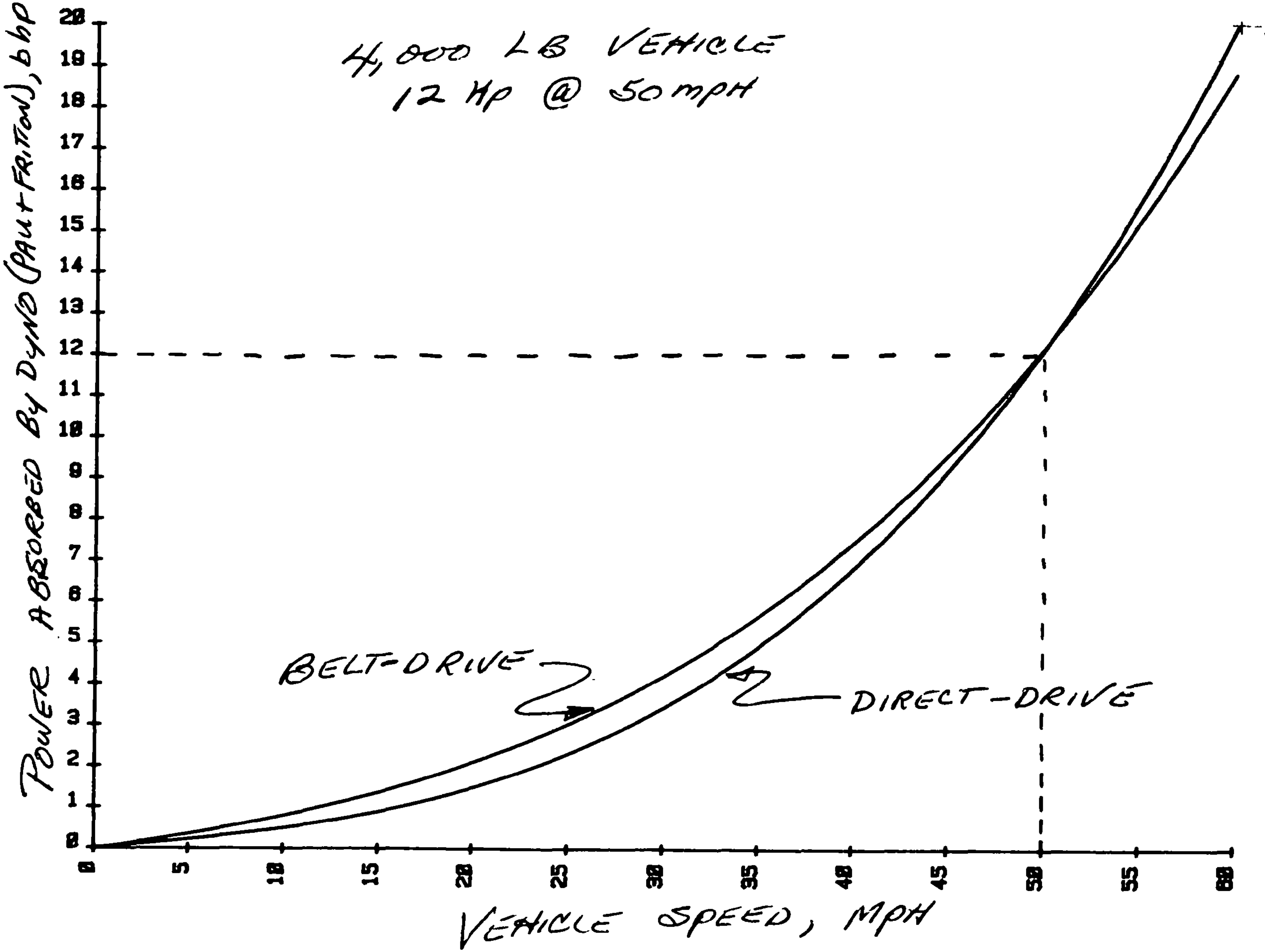
VIMA bg
6-27-77


Comparison of Schenck Eddy Current and Water Brake Dynamometer
kpm
ft.lbs.
9
8
7
6
5
4
3
2
1
0
60
50
40
30
20
10
Water Brake
Eddy Current Brake
IW : 3500 lbs.
Load: 8.8 HP (31 kp) at 80 km/h (50 mph)
VIMA bg
6-27-77
0
20
40
60
80
100
km/h
0
10
20
30
40
50
60
mph



SUBMITTED BY JIM CHASE 6/29/77
BARTLESVILLE, OKLAHOMA

ERDA
BERC



SUBMITTED BY JIM CHASE 6/29/77
BARTLESVILLE, OKLAHOMA

ERDA
BERC

JOC

Inter Office Communication · CAR ENGINEERING GROUP

September 8, 1976

Mr. A. S. Myint

PRESENTED BY:
J. F. MEEK
FORD MOTOR COMPANY

cc P. Bandoian
G. A. Byberg
T. J. Cavanaugh
H. F. Copp
M. H. Goemer
W. E. Jackson
G. R. Jones
C. W. LaPointe
N. E. Prochaska
R. A. Rousos
B. H. Simpson

Subject: Clayton Chassis Dynamometer Friction Survey

Objective

To determine the average friction level of the Clayton CTE-50 (emissions testing) chassis dynamometer so the dynamometer system can be modeled for use in the Test Operations Fuel Economy Projection (TOFEP) program.

Background

Vehicle operation on a Clayton chassis dynamometer can be modeled to predict fuel economy if the vehicle tire operating on the dynamometer and the dynamometer itself can be modeled. Studies have been made and are continuing to determine the tire/roll interface model.

In addition to the tire reaction on the dynamometer, the basic characteristic of the dynamometer must be determined. This includes the dynamometer friction and the characteristic curve of the power absorption unit (P.A.U.).

This report describes the friction characteristics of the dynamometer system. The friction results from the bearings that support the front and rear dynamometer rolls. Also a portion of the friction results from the inertia weight system friction (and windage). The dynamometer friction at 50 mph is normally determined during calibration and the P.A.U. level is set to make the total dynamometer horsepower (friction horsepower plus P.A.U. horsepower) equal to a value prescribed by the EPA. This prescribed value is commonly referred to as the "cookbook hp". As a result the dynamometer absorption characteristics at 50 mph are defined, but allowed to "fall where they may" at other speeds.

Summary of Results

Six of the Emission Laboratories Department Clayton CTE-50 chassis dynamometers were involved in this test. All the dynamometers were equipped with 8.65 inch diameter rolls spaced on 17.25 inch centers. The systems tested were:

Dynamometer Cell Number	Location
8	ETL
13	ETL
14	ETL
16	ETL
28	APTL
29	APTL

The dynamometer friction levels were tested at 2500, 3000, 4000, and 5500 inertia weight settings on all dynamometers except numbers 28 and 29. These dynamometers were tested at all inertia settings (1750, 2000, 2250, 2500, 2750, 3000, 3500, 4000, 4500, 5000, and 5500).

Based on regression analysis the dynamometer friction is a linear function of dynamometer speed. The variation in dynamometer front roll/inertia system friction at zero speed was small, ranging from .9 ft-lb to 1.7 ft-lb of friction torque. At 50 mph the friction variation was larger. As an example, at 2500 lb inertia weight the friction varied from a low of 2.5 ft-lb on cell 16 to a high of 7.5 ft-lb on cell 28.

The friction characteristics for the individual dynamometers are presented on page 6 . This includes the constants from the regression analysis plus the calculated friction at 50 mph. The regression equation is as follows:

$$T_f = A + BV$$

where: T_f = friction torque; ft-lb

V = roll speed, mph

A & B = constants

The test results from which the regression analysis was made are tabulated on page 10 through 22.

In addition to the data for individual dynamometer cells, a typical dynamometer friction level was developed for each inertia weight class. Using the general equation for dynamometer friction, the friction characteristics for each inertia class are shown below. These are graphically shown on page 8 .

Inertia Class	Equation Constants A	Equation Constants B	Friction Torque at 50 mph, ft-lb
1750	.76	.0585	3.68
2000	.81	.0691	4.26
2250	.84	.0738	4.53
2500	.89	.0844	5.11
2750	.89	.0765	4.72
3000	.94	.0871	5.30
3500	1.02	.1024	6.14
4000	.99	.0926	5.62
4500	1.07	.1079	6.46
5000	1.12	.1106	6.65
5500	1.20	.1259	7.50
Rear Rolls	.361	.0091	.82

The effects of the dynamometer friction variation on the EPA fuel economy tests were evaluated using TOFEP. The dynamometers are calibrated at 50 mph so the friction effects at 50 mph are taken into account, but at other speeds the friction variations will effect the dynamometer load. The fuel economies for two different inertia weight class vehicles were projected using the lowest and highest dynamometer friction levels. The results are as follows in miles per gallon:

E.P.A. Test Sequence	2500 I.W. Vehicle 2.3L Engine High Friction	Low Friction	Diff.	5500 I.W. Vehicle 460 CID Engine High Friction	Low Friction	Diff.
CVS-CH	28.40	28.74	.34	9.38	9.43	.05
HWFET	36.11	36.22	.11	14.42	14.45	.03
M-H	31.42	31.68	.26	11.13	11.18	.05

Test Method

The dynamometer friction was determined by the coast down method which is commonly used to calibrate this type of dynamometer. The dynamometer is "warmed-up" prior to the friction test by operating a vehicle on it at 50 mph for at least fifteen minutes. After warm-up the vehicle speed is increased to somethingin excess of 60 mph and then the vehicle is lifted off the dynamometer with an air jack. The dynamometer is allowed to coast down. During the coast down the front and rear roll speeds and P.A.U. torque are continuously recorded on an oscillograph. The total torque on the dynamometer at a given instant of time is determined from the deceleration rate at that point in time and the mass being decelerated. The deceleration rate is determined from the slope of the time/speed recorded trace. The P.A.U. torque is subtracted from the total torque determined and the remainder is friction torque. In the instance of the rear roll there is no P.A.U. torque and therefore the total torque is the friction torque.

Discussion

Although most readers have an understanding of the Clayton dynamometer inertia system, it may be of value to review the system. The inertia system consists of five rotating weights which are direct driven by the front roll of the dynamometer. One of the weights is a trim weight which is permanently attached to the system to bring the minimum system inertia to 1750 lb. The other four weights represent inertia values of 250 lbs, 500 lbs, 1000 lbs and 2000 lbs. These inertia weights are each supported on separate bearings and each weight has its own clutch to connect it to the front roll. These clutches are engaged in various combinations to provide inertia simulation up to 5500 lbs. The combinations of weights for each inertia value are as follows:

Total Inertia-lb	Inertia Weights-lb 250	500	1000	2000
1750				
2000	X			
2250		X		
2500	X	X		
2750			X	
3000	X		X	
3500	X	X	X	
4000	X			X
4500	X	X		X
5000	X		X	X
5500	X	X	X	X

Although the casual observer may expect that dynamometer friction increases with inertia load, this does not necessarily happen. Typically the dynamometer friction at the 2750 lb setting maybe less than at the 2500 lb setting and the friction at the 4000 setting may be less than at the 3500 lb setting. Although the friction level increases with the size of the weights, the friction level also increases with the number of weights used for a given inertia setting. As seen on the above chart the 2750 lb inertia setting requires one weight and the 2500 lb inertia setting requires two weights and the 4000 lb inertia setting requires two weights and the 3500 lb inertia setting requires three weights. Individual friction levels for each of the four system inertia weights was developed from the data and that is how the typical dynamometer friction level data on sheet 2 was developed. The equation for each weight is as follows:

Inertia Weight Wt.	Equation Constants A	B	Friction Torque at 50 mph, ft-lb	FHp @50 = $\frac{T \times 50}{135.14}$
Minimum (1750)	.76	.0585	3.69	1.365
250	.05	.0106	.58	.214
500	.08	.0153	.85	.314
1000	.13	.0180	1.03	.381
2000	.18	.0235	1.36	.503

The above data is shown graphically on sheet 9 .

Some problems were encountered in the data analysis. Although tests were conducted on six Clayton chassis dynamometer systems a complete data analysis was only reported for five systems. The calculated friction on the front roll of the dynamometer in cell number 13 appeared to be unreasonably low. Subsequent investigation found the load cell system malfunctioning. The front roll data from cell number 13 was not used in any of the analysis. The rear roll friction data for cell number 8 was not used in the analysis. The roll friction was quite high (up to 1.50 ft-lb at 50 mph) and quite variable. The friction torque at 50 mph varied from a low of .87 ft-lb up to 1.50 ft-lb. It was suspected that something may have been dragging on the roll, but this was never verified.

The rear roll configuration for all the dynamometers was not the same. The left and right rolls are connected together with a shaft in cells 28 and 29. The left and right rolls were not connected together in the other cells. (At the time the tests were conducted a project had been implemented to connect the rolls together). In the instance where the rear rolls were not connected together the friction was measured on one roll and then multiplied by two to get the total rear roll friction.

Although not a part of the planned test program, the shape of the P.A.U. torque absorption curve was examined. A paper published in February 1976 by M. W. Feiferman of the EPA indicates the P.A.U. absorbed torque is a function of the speed to the 1.83 power. A regression analysis of the P.A.U. torque data from the dynamometer friction tests was made for each of the five dynamometers evaluated. The exponents for the P.A.U. torque curves were as follows:

Dynamometer Cell No.	Exponent
8	2.25
14	2.00
16	2.35
28	2.10
29	2.20
Average	2.18

J. F. Meek

J. F. Meek
Advanced Methods & Technology Dept.

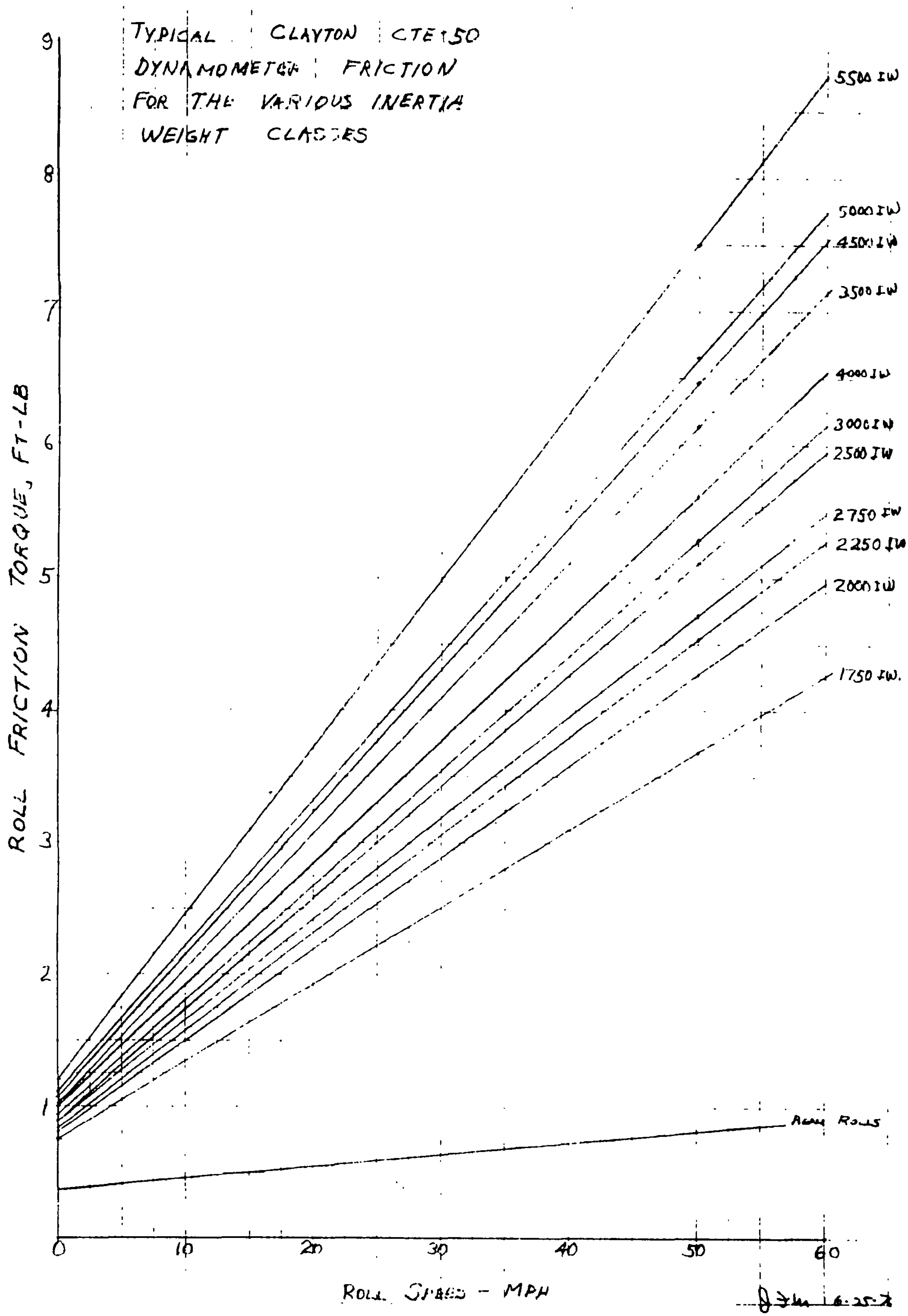
FRONT ROLL FRICTION

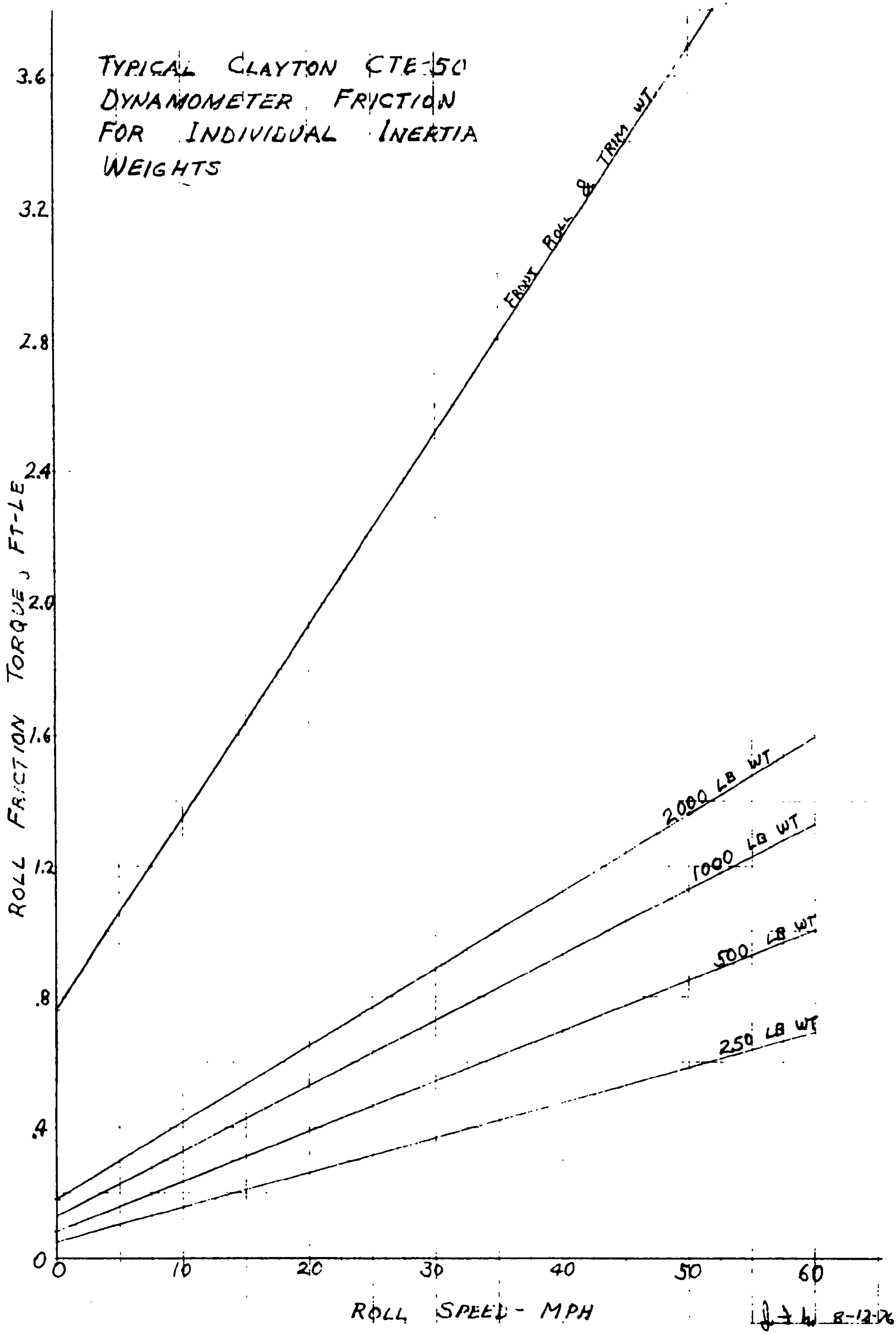
Cell No.	Inertia Wt Class	Regression Equation Constants A	B	Standard Error Estimate	Correlation Coefficient	Friction Torque ft-lb @ 50 mph
8	2500	1.346	.1109	.398	.988	6.89
	3000	1.472	.1094	.165	.998	6.94
	4000	1.533	.1137	.377	.989	7.22
	5500	1.694	.1555	.295	.996	9.47
14	2500	1.445	.0332	.090	.992	3.11
	3000	1.397	.0340	.207	.961	3.10
	4000	1.543	.0242	.370	.817	2.75
	5500	1.443	.0797	.369	.978	5.43
16	2500	1.246	.0257	.237	.922	2.53
	3000	1.082	.0326	.216	.957	2.71
	4000	1.296	.0381	.220	.969	3.20
	5500	1.141	.0862	.204	.994	5.45
28	1750	1.171	.0801	.372	.979	5.18
	2000	1.298	.0951	.286	.990	6.05
	2250	1.129	.1145	.518	.980	6.46
	2500	1.275	.1250	.532	.984	7.53
	2750	.834	.1366	.798	.967	7.66
	3000	1.137	.1395	.718	.974	8.11
	3500	1.105	.1661	1.077	.960	9.41
	4000	1.237	.1331	.621	.979	7.89
	4500	1.402	.1515	.679	.980	8.98
	5000	1.063	.1785	.931	.974	9.99
	5500	1.373	.1893	.875	.979	10.84
29	1750	.760	.0585	.172	.991	3.69
	2000	1.135	.0564	.183	.988	3.20
	2250	.869	.0764	.226	.990	4.69
	2500	1.017	.0851	.173	.995	5.27
	2750	1.009	.0720	.137	.996	4.61
	3000	.960	.0909	.252	.992	5.51
	3500	1.126	.1076	.313	.992	6.51
	4000	.954	.0885	.211	.994	5.38
	4500	.946	.1024	.340	.989	6.07
	5000	.923	.1117	.244	.995	6.51
	5500	1.003	.1346	.252	.996	7.73

Continued on sheet 7

REAR ROLL FRICTION

Cell No.	Regression Constants A	Regression Constants B	Standard Error Estimate ft-lb	Correlation Coefficient	Friction Torque ft-lb @ 50 mph ft-lb
13	.191	.0102	.052	.970	.70
14	.426	-.0003	.039	.122	.43
16	.411	.0102	.061	.959	.92
28	.606	.0140	.084	.961	1.31
29	.171	.0113	.042	.982	.74


TYPICAL CLAYTON CTE-50
DYNAMOMETER FRICTION
FOR THE VARIOUS INERTIA
WEIGHT CLASSES
ROLL FRICTION TORQUE, FT-LB
ROLL SPEED - MPH
0
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
5500 IW
5000 IW
4500 IW
3500 IW
4000 IW
3000 IW
2500 IW
2750 IW
2250 IW
2000 IW
1750 IW.
REAR ROLLS


TYPICAL CLAYTON CTE-50
DYNAMOMETER FRICTION
FOR INDIVIDUAL INERTIA
WEIGHTS
FRONT ROLL & TRIM WT.
2000 LB WT
1000 LB WT
500 LB WT
250 LB WT
ROLL FRICTION TORQUE, FT-LB
ROLL SPEED - MPH
0
.4
.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
0
10
20
30
40
50
60
8-12-76

JM08F

CLAYTON DYNAMOMETER FRICTION STUDY

FRONT ROLLS - CELL NUMBER 8
TEST DATE: JUNE 7, 1976

NOMINAL SPEED MPH	C.D.* SPEED MPH	C.D.* TIME SEC	TOTAL TORQUE FT-LB	TOTAL HP	PAU TORQUE FT-LB	FRICTION TORQUE FT-LB
INERTIA WEIGHT CLASS - 2500						
60	65-55	9.2	41.9	18.62	33.3	8.58
55	60-50	11.0	35.1	14.27	27.7	7.32
50	55-45	13.2	29.2	10.81	22.2	6.97
40	45-35	20.4	18.9	5.60	13.6	5.26
30	34-26	26.9	11.5	2.55	7.2	4.27
20	23-17	36.0	6.4	0.95	3.0	3.43
10	12- 8	48.6	3.2	0.23	0.5	2.68
5	6- 4	35.0	2.2	0.08	0.0	2.20
INERTIA WEIGHT CLASS - 3000						
60	65-55	11.2	41.8	18.54	33.6	8.17
55	60-50	13.2	35.4	14.42	27.9	7.54
50	55-45	15.8	29.6	10.95	22.6	7.01
40	45-35	24.2	19.3	5.72	13.6	5.68
30	34-26	31.8	11.8	2.61	7.2	4.52
20	23-17	43.0	6.5	0.97	3.0	3.53
10	12- 8	58.0	3.2	0.24	0.5	2.68
5	6- 4	43.0	2.2	0.08	0.0	2.18
INERTIA WEIGHT CLASS - 4000						
60	65-55	14.7	43.0	19.09	34.4	8.59
55	60-50	17.2	36.7	14.95	28.5	8.24
50	55-45	21.3	29.7	10.98	22.9	6.77
40	45-35	32.2	19.6	5.81	13.6	5.98
30	34-26	43.2	11.7	2.60	7.2	4.55
20	23-17	58.0	6.5	0.97	3.0	3.54
10	12- 8	76.0	3.3	0.25	0.3	3.03
5	6- 4	56.0	2.3	0.08	0.0	2.26
INERTIA WEIGHT CLASS - 5500						
55	60-50	22.7	38.7	15.74	28.4	10.29
50	55-45	27.0	32.5	12.03	22.7	9.78
40	45-35	40.8	21.5	6.37	13.7	7.83
30	34-26	53.0	13.3	2.94	7.3	5.96
20	23-17	69.0	7.6	1.13	3.1	4.54
10	12- 8	88.0	4.0	0.30	0.6	3.34
6	7- 5	57.0	3.1	0.14	0.2	2.93

DONE
SCR

* C.D. means "Coast Down"

RUN
JM14F

CLAYTON DYNAMOMETER FRICTION STUDY

FRONT ROLLS - CELL NUMBER 14
TEST DATE: JUNE 16, 1976

NOMINAL SPEED MPH	C.D. SPEED MPH	C.D. TIME SEC	TOTAL TORQUE FT-LB	TOTAL HP	PAU TORQUE FT-LB	FRICTION TORQUE FT-LB
INERTIA WEIGHT CLASS - 2500						
60	65-55	9.9	39.0	17.30	35.7	3.32
55	60-50	11.4	33.8	13.77	30.5	3.34
50	55-45	13.6	28.4	10.49	25.3	3.07
40	45-35	20.2	19.1	5.65	16.2	2.90
30	34-26	26.3	11.7	2.60	9.3	2.43
20	23-17	34.6	6.7	0.99	4.5	2.19
12	14-10	45.5	3.4	0.30	1.6	1.79
9	10- 8	31.0	2.5	0.17	0.8	1.69
INERTIA WEIGHT CLASS - 3000						
60	65-55	11.9	39.3	17.45	35.7	3.61
55	60-50	13.9	33.7	13.70	30.7	3.01
50	55-45	16.6	28.2	10.43	25.3	2.88
40	45-35	24.5	19.1	5.65	16.1	3.00
30	34-26	31.4	11.9	2.65	9.4	2.57
20	23-17	41.4	6.8	1.00	4.6	2.18
12	14-10	55.0	3.4	0.30	1.7	1.70
9	10- 8	36.0	2.6	0.17	1.0	1.60
INERTIA WEIGHT CLASS - 4000						
60	65-55	16.3	38.8	17.21	36.4	2.37
55	60-50	18.6	34.0	13.83	31.0	2.93
50	55-45	22.1	28.6	10.58	25.6	3.00
40	45-35	33.2	19.0	5.65	[illegible]	3.04
30	34-26	42.9	11.8	2.62	9.4	2.39
20	23-17	55.5	6.8	1.01	4.7	2.08
11	13- 9	81.0	3.1	0.25	1.5	1.62
8	9- 7	55.0	2.3	0.14	0.8	1.55
INERTIA WEIGHT CLASS - 5500						
60	65-55	20.0	43.9	19.49	38.2	5.66
55	60-50	23.2	37.9	15.41	31.5	6.41
50	55-45	28.2	31.1	11.52	25.5	5.69
40	45-35	43.0	20.4	6.04	15.9	4.52
30	34-26	54.2	13.0	2.88	9.4	3.61
20	23-17	68.0	7.7	1.15	4.7	3.00
11	13- 9	93.5	3.8	0.31	1.5	2.26
8	9- 7	59.0	3.0	0.18	0.8	2.23

DONE
SCR

RUN
JM16F

CLAYTON DYNAMOMETER FRICTION STUDY

$$\frac{(IW-148)(V_1^2-V_2^2)}{2g\,550\,\Delta t} = \frac{T \times 50}{135.14}$$

FRONT ROLLS - CELL NUMBER 16
TEST DATE: JUNE 19, 1976

NOMINAL SPEED MPH	C.D. SPEED MPH	C.D. TIME SEC	TOTAL TORQUE FT-LB	TOTAL HP	PAU TORQUE FT-LB	FRICTION TORQUE FT-LB
INERTIA WEIGHT CLASS - 2500						
60	65-55	9.7	39.8	17.66	37.1	2.67
55	60-50	11.6	33.3	13.53	30.7	2.51
50	55-45	14.3	27.0	9.98	24.5	2.48
40	45-35	22.5	17.1	5.07	14.7	2.45
30	34-26	30.5	10.1	2.25	7.6	2.47
20	23-17	43.6	5.3	0.79	3.5	1.81
10	12- 8	63.5	2.4	0.18	1.1	1.33
8	9- 7	38.0	2.0	0.12	0.8	1.28
INERTIA WEIGHT CLASS - 3000						
60	65-55	11.5	40.7	18.06	37.3	3.33
55	60-50	14.0	33.4	13.60	30.9	2.52
50	55-45	17.1	27.4	10.12	24.7	2.61
40	45-35	27.4	17.1	5.05	14.6	2.42
30	34-26	37.3	10.0	2.23	7.7	2.28
20	23-17	53.0	5.3	0.78	3.6	1.75
10	12- 8	79.0	2.4	0.18	1.0	1.32
8	9- 7	46.0	2.0	0.12	0.7	1.33
INERTIA WEIGHT CLASS - 4000						
60	65-55	15.4	41.0	18.22	37.7	3.34
55	60-50	18.4	34.3	13.98	30.9	3.50
50	55-45	22.5	28.1	10.39	24.5	3.59
40	45-35	36.2	17.5	5.17	14.5	2.91
30	34-26	48.7	10.4	2.30	7.6	2.73
20	23-17	69.0	5.5	0.81	3.5	2.00
10	12- 8	96.0	2.6	0.19	1.0	1.58
9	10- 8	53.0	2.4	0.16	0.8	1.63
INERTIA WEIGHT CLASS - 5500						
60	65-55	20.0	43.9	19.49	37.7	6.16
55	60-50	23.7	37.1	15.08	30.8	6.26
50	55-45	29.4	29.9	11.05	24.7	5.22
40	44-36	36.8	19.1	5.65	14.5	4.59
30	33-27	46.1	11.4	2.54	7.6	3.78
20	22-18	56.5	6.2	0.92	3.5	2.72
10	11- 9	56.5	3.1	0.23	1.1	2.01
8	9- 7	66.0	2.7	0.16	0.8	1.91

DONE
SCR

CLAYTON DYNAMOMETER FRICTION STUDY

FRONT ROLLS - CELL NUMBER 28
TEST DATE: JUNE 4, 1976

NOMINAL SPEED MPH	C.D. SPEED MPH	C.D. TIME SEC	TOTAL TORQUE FT-LB	TOTAL HP	PAU TORQUE FT-LB	FRICTION TORQUE FT-LB
INERTIA WEIGHT CLASS - 1750						
60	65-55	6.7	39.2	17.40	33.2	5.98
55	60-50	8.0	32.8	13.36	27.5	5.38
50	55-45	9.3	28.2	10.45	22.6	5.69
40	45-35	14.3	18.4	5.44	13.9	4.50
30	34-26	19.3	10.9	2.42	7.9	3.03
20	23-17	27.0	5.8	0.86	3.4	2.44
10	12- 8	36.0	2.9	0.22	0.7	2.24
5	6- 4	30.0	1.8	0.06	0.0	1.75
INERTIA WEIGHT CLASS - 2000						
55	60-50	8.8	34.5	14.04	27.7	6.77
50	55-45	10.5	28.9	10.70	22.7	6.18
40	45-35	16.1	18.9	5.58	13.9	4.94
30	34-26	21.2	11.5	2.54	7.7	3.75
20	23-17	29.2	6.2	0.92	3.2	2.99
10	12- 8	38.2	3.2	0.24	0.6	2.55
5	6- 4	30.5	2.0	0.07	0.1	1.89
INERTIA WEIGHT CLASS - 2250						
60	65-55	8.2	42.0	18.66	33.4	8.67
55	60-50	9.7	35.5	14.46	28.0	7.55
50	55-45	11.7	29.5	10.90	22.8	6.67
40	45-35	18.0	19.2	5.67	14.1	5.09
30	34-26	23.7	11.6	2.58	7.4	4.26
20	23-17	32.4	6.4	0.94	3.5	2.89
10	12- 8	41.4	3.3	0.25	0.7	2.65
6	7- 5	29.0	2.4	0.11	0.1	2.28
INERTIA WEIGHT CLASS - 2500						
60	65-55	9.0	42.9	19.03	33.5	9.40
55	60-50	10.6	36.4	14.81	28.0	8.36
50	55-45	12.7	30.4	11.24	22.8	7.58
40	45-35	19.5	19.8	5.86	14.3	5.52
30	34-26	25.4	12.2	2.70	7.8	4.34
20	23-17	33.8	6.8	1.01	3.4	3.40
10	12- 8	41.1	3.8	0.28	0.8	2.98
5	6- 4	33.0	2.3	0.09	0.0	2.29
2	3- 1	48.0	1.6	0.02	0.0	1.61
INERTIA WEIGHT CLASS - 2750						
60	65-55	9.8	43.6	19.33	33.2	10.33
55	60-50	11.8	36.2	14.72	27.9	8.23
50	55-45	14.3	29.8	11.04	22.7	7.10
40	45-35	21.4	19.9	5.90	14.1	5.88
30	34-26	28.7	11.9	2.64	7.9	4.04
20	23-17	38.4	6.7	0.99	3.5	3.13
10	12- 8	49.5	3.4	0.26	0.7	2.72
6	7- 5	37.0	2.3	0.10	0.0	2.26
INERTIA WEIGHT CLASS - 3000						
60	65-55	10.7	43.7	19.41	33.2	10.50
55	60-50	12.6	37.1	15.11	27.9	9.19

FRONT ROLLS - CELL NUMBER 28 (CONTINUED)

NOMINAL SPEED MPH	C.D. SPEED MPH	C.D. TIME SEC	TOTAL TORQUE FT-LB	TOTAL HP	PAU TORQUE FT-LB	FRICTION TORQUE FT-LB
50	55-45	15.5	30.2	11.17	22.8	7.39
40	45-35	23.2	20.2	5.97	14.1	6.05
30	34-26	30.0	12.5	2.77	7.8	4.72
20	23-17	40.4	6.9	1.03	3.4	3.55
10	12- 8	49.5	3.8	0.28	0.8	3.00
6	7- 5	37.5	2.5	0.11	0.0	2.50
INERTIA WEIGHT CLASS - 3500						
60	65-55	11.9	46.2	20.52	33.7	12.50
55	60-50	14.1	39.0	15.87	28.1	10.87
50	55-45	17.5	31.4	11.63	22.9	8.48
40	45-35	26.0	21.2	6.26	14.7	6.46
30	34-26	33.6	13.1	2.91	7.8	5.33
20	23-17	44.0	7.5	1.11	3.6	3.86
10	12- 8	52.5	4.2	0.31	0.7	3.46
6	7- 5	38.0	2.9	0.13	0.0	2.89
INERTIA WEIGHT CLASS - 4000						
60	65-55	14.4	43.9	19.48	34.0	9.94
55	60-50	17.2	36.7	14.95	27.9	8.81
50	55-45	20.5	30.8	11.41	23.0	7.79
40	45-35	31.6	20.0	5.92	14.2	5.79
30	34-26	40.9	12.4	2.74	7.8	4.55
20	23-17	53.2	7.1	1.05	3.6	3.49
10	12- 8	67.5	3.7	0.28	0.7	3.02
6	7- 5	48.0	2.6	0.12	0.0	2.58
INERTIA WEIGHT CLASS - 4500						
60	65-55	15.8	45.2	20.06	34.0	11.15
55	60-50	18.5	38.6	15.71	28.5	10.08
50	55-45	22.1	32.3	11.95	23.4	8.89
40	45-35	33.8	21.1	6.25	14.3	6.87
30	34-26	43.0	13.3	2.95	8.4	4.89
20	23-17	55.5	7.7	1.14	3.6	4.08
10	12- 8	69.5	4.1	0.30	0.8	3.33
6	7- 5	48.0	3.0	0.13	0.0	2.98
INERTIA WEIGHT CLASS - 5000						
60	65-55	16.8	47.4	21.04	34.4	12.96
55	60-50	19.8	40.2	16.36	28.8	11.40
50	55-45	24.2	32.9	12.17	23.6	9.28
40	45-35	35.9	22.2	6.56	14.9	7.24
30	34-26	45.3	14.1	3.12	8.4	5.62
20	23-17	56.0	8.5	1.26	4.6	3.97
10	12- 8	61.0	5.2	0.39	1.7	3.47
6	7- 5	43.0	3.7	0.16	0.8	2.93
INERTIA WEIGHT CLASS - 5500						
60	65-55	18.3	48.0	21.31	34.2	13.75
55	60-50	21.7	40.5	16.47	28.3	12.20
50	55-45	26.0	33.8	12.50	23.3	10.50
40	45-35	39.5	22.2	6.58	14.2	8.02
30	34-26	50.5	13.9	3.09	7.9	6.06
20	23-17	63.5	8.3	1.23	3.7	4.56
10	12- 8	74.6	4.7	0.35	0.9	3.79
7	8- 6	47.0	3.7	0.19	0.1	3.59

FRONT ROLLS - CELL NUMBER 29
TEST DATE: MAY 27, 1976

NOMINAL SPEED MPH	C.D. SPEED MPH	C.D. TIME SEC	TOTAL TORQUE FT-LB	TOTAL HP	PAU TORQUE FT-LB	FRICTION TORQUE FT-LB
INERTIA WEIGHT CLASS - 1750						
55	60-50	7.4	35.5	14.44	31.5	3.99
50	55-45	8.8	29.8	11.04	25.9	3.95
40	45-35	13.7	19.2	5.67	16.2	2.92
30	34-26	18.8	11.2	2.48	8.9	2.28
20	23-17	27.3	5.8	0.85	3.9	1.87
10	12- 8	39.8	2.6	0.20	1.2	1.44
5	6- 4	29.5	1.8	0.07	0.6	1.13
2	3- 1	35.0	1.5	0.02	0.6	0.90
INERTIA WEIGHT CLASS - 2000						
55	60-50	8.6	35.3	14.37	31.2	4.06
50	55-45	10.1	30.1	11.12	25.8	4.27
40	45-35	15.6	19.5	5.76	16.2	3.27
30	34-26	20.9	11.6	2.58	8.9	2.72
20	23-17	29.1	6.3	0.93	3.9	2.36
10	12- 8	41.6	2.9	0.22	1.2	1.72
5	6- 4	30.5	2.0	0.07	0.6	1.39
INERTIA WEIGHT CLASS - 2250						
55	60-50	9.3	37.1	15.08	31.7	5.37
50	55-45	11.2	30.8	11.39	26.1	4.68
40	45-35	17.3	19.9	5.90	16.2	3.73
30	34-26	23.3	11.8	2.63	8.9	2.94
20	23-17	33.2	6.2	0.92	4.0	2.23
10	12- 8	46.5	3.0	0.22	1.2	1.72
5	6- 4	33.5	2.1	0.08	0.6	1.46
INERTIA WEIGHT CLASS - 2500						
55	60-50	10.2	37.8	15.39	32.0	5.82
50	55-45	12.2	31.6	11.70	26.2	5.42
40	45-35	18.9	20.4	6.04	16.2	4.21
30	34-26	25.4	12.2	2.70	8.8	3.35
20	23-17	35.1	6.6	0.98	3.9	2.69
10	12- 8	47.7	3.2	0.24	1.2	1.98
5	6- 4	35.5	2.2	0.08	0.6	1.52
INERTIA WEIGHT CLASS - 2750						
55	60-50	11.5	37.1	15.10	32.0	5.11
50	55-45	13.9	30.7	11.36	26.3	4.41
40	45-35	21.1	20.2	5.99	16.2	4.03
30	34-26	28.9	11.8	2.62	8.7	3.06
20	23-17	40.5	6.3	0.94	3.9	2.42
10	12- 8	58.0	2.9	0.22	1.2	1.74
5	6- 4	42.5	2.0	0.07	0.6	1.41
INERTIA WEIGHT CLASS - 3000						
55	60-50	12.2	38.3	15.61	32.0	6.35
50	55-45	14.8	31.6	11.69	26.4	5.21
40	45-35	22.5	20.8	6.15	16.2	4.59
30	34-26	30.5	12.3	2.72	8.7	3.52
20	23-17	42.9	6.5	0.97	3.9	2.64
10	12- 8	59.1	3.2	0.23	1.2	1.92
5	6- 4	43.0	2.2	0.08	0.6	1.58

FRONT ROLLS - CELL NUMBER 29 (CONTINUED)

NOMINAL SPEED MPH	C.D. SPEED MPH	C.D. TIME SEC	TOTAL TORQUE FT-LB	TOTAL HP	PAU TORQUE FT-LB	FRICTION TORQUE FT-LB
INERTIA WEIGHT CLASS - 3500						
60	65-55	11.7	47.0	20.87	38.9	8.10
55	60-50	13.9	39.6	16.10	32.5	7.06
50	55-45	16.8	32.7	12.11	26.5	6.23
40	45-35	25.7	21.4	6.33	16.2	5.20
30	34-26	34.2	12.9	2.86	8.8	4.06
20	23-17	46.6	7.1	1.05	3.9	3.18
10	12- 8	62.3	3.5	0.26	1.2	2.28
5	6- 4	43.0	2.6	0.09	0.6	1.96
INERTIA WEIGHT CLASS - 4000						
60	65-55	13.8	45.8	20.33	39.3	6.45
55	60-50	16.4	38.5	15.68	32.7	5.84
50	55-45	19.8	31.9	11.81	26.4	5.52
40	45-35	31.1	20.3	6.01	16.1	4.22
30	34-26	41.7	12.1	2.69	8.8	3.32
20	23-17	58.0	6.5	0.97	3.9	2.64
10	12- 8	78.5	3.2	0.24	1.2	1.97
5	6- 4	57.0	2.2	0.08	0.6	1.57
INERTIA WEIGHT CLASS - 4500						
60	65-55	14.0	51.0	22.64	43.5	7.51
55	60-50	16.7	42.8	17.40	36.0	6.76
50	55-45	20.5	34.8	12.89	29.2	5.58
40	45-35	31.3	22.8	6.75	17.7	5.06
30	34-26	42.4	13.5	2.99	9.7	3.72
20	23-17	59.0	7.3	1.07	4.5	2.76
10	12- 8	82.0	3.5	0.26	1.4	2.08
5	6- 4	58.0	2.5	0.09	0.7	1.76
INERTIA WEIGHT CLASS - 5000						
60	65-55	18.7	42.6	18.90	34.7	7.83
55	60-50	22.2	35.9	14.59	28.7	7.11
50	55-45	26.7	29.8	11.03	23.2	6.62
40	45-35	41.1	19.4	5.73	14.2	5.17
30	34-26	54.0	11.8	2.62	7.9	3.89
20	23-17	72.3	6.6	0.98	3.6	3.01
10	12- 8	93.6	3.4	0.25	1.2	2.15
5	6- 4	65.0	2.4	0.09	0.7	1.75
INERTIA WEIGHT CLASS - 5500						
60	65-55	15.7	55.9	24.83	46.7	9.19
55	60-50	18.9	46.5	18.91	37.7	8.72
50	55-45	23.1	38.0	14.07	30.4	7.62
40	45-35	35.9	24.5	7.24	18.2	6.21
30	34-26	48.2	14.6	3.24	9.9	4.68
20	23-17	65.3	8.1	1.19	4.5	3.57
10	12- 8	91.6	3.8	0.28	1.4	2.44
6	7- 5	60.0	2.9	0.13	0.9	2.08

DONE
SCR

GÊT-JM08R
APP-JMTEMP

RUN
JM08R

CLAYTON DYNAMOMETER FRICTION STUDY

REAR ROLLS - CELL NUMBER 8
TEST DATE: JUNE 7, 1976

NOMINAL SPEED MPH	COAST DOWN SPEED MPH	C.D. TIME SEC	FRICTION TORQ FT-LB	HP
65.9	70.8-61.0	20	1.20	0.58
54.8	61.0-48.7	20	1.50	0.61
42.6	48.7-36.5	20	1.49	0.47
31.6	36.5-26.7	20	1.20	0.28
22.2	26.7-17.7	20	1.10	0.18
13.5	17.7- 9.2	20	1.04	0.10
5.2	9.2- 1.1	20	0.99	0.04
66.9	70.5-63.3	20	0.88	0.44
59.9	63.3-56.5	20	0.83	0.37
53.0	56.5-49.5	20	0.86	0.34
45.9	49.5-42.3	20	0.88	0.30
39.0	42.3-35.7	20	0.81	0.23
32.3	35.7-29.0	20	0.82	0.20
25.7	29.0-22.3	20	0.82	0.16
19.3	22.3-16.3	20	0.73	0.10
13.5	16.3-10.7	20	0.69	0.07
8.1	10.7- 5.4	20	0.65	0.04
2.7	5.4- 0.0	20	0.66	0.01
68.4	72.4-64.5	20	0.97	0.49
60.7	64.5-56.9	20	0.93	0.42
52.9	56.9-48.9	20	0.98	0.38
45.2	48.9-41.4	20	0.92	0.31
38.1	41.4-34.7	20	0.82	0.23
31.3	34.7-27.9	20	0.83	0.19
24.5	27.9-21.0	20	0.84	0.15
17.6	21.0-14.2	20	0.83	0.11
11.0	14.2- 7.7	20	0.80	0.06
4.9	7.7- 2.1	20	0.69	0.02
57.8	62.1-53.6	20	1.04	0.45
49.3	53.6-45.1	20	1.04	0.38
41.3	45.1-37.6	20	0.92	0.28
33.9	37.6-30.2	20	0.91	0.23
26.6	30.2-22.9	20	0.89	0.18
19.5	22.9-16.0	20	0.84	0.12
12.6	16.0- 9.3	20	0.82	0.08
6.4	9.3- 3.6	20	0.70	0.03

DONE
SCR

RUN
JM13R

CLAYTON DYNAMOMETER FRICTION STUDY

REAR ROLLS - CELL NUMBER 13
TEST DATE: JUNE 8, 1976

NOMINAL SPEED MPH	COAST DOWN SPEED MPH	C.D. TIME SEC	FRICTION TORQ FT-LB	HP
63.0	66.0-60.0	20	0.73	0.34
57.1	60.0-54.1	20	0.72	0.30
51.4	54.1-48.7	20	0.66	0.25
46.1	48.7-43.5	20	0.64	0.22
41.2	43.5-38.8	20	0.58	0.18
36.5	38.8-34.2	20	0.56	0.15
32.1	34.2-30.0	20	0.51	0.12
28.0	30.0-26.0	20	0.49	0.10
24.0	26.0-22.1	20	0.48	0.08
20.2	22.1-18.3	20	0.46	0.07
16.7	18.3-15.0	20	0.40	0.05
13.5	15.0-12.0	20	0.37	0.04
10.5	12.0- 9.0	20	0.37	0.03
7.7	9.0- 6.4	20	0.32	0.02
5.3	6.4- 4.2	20	0.27	0.01
3.2	4.2- 2.3	20	0.23	0.01
1.6	2.3- 0.9	20	0.17	0.00
64.7	68.0-61.5	20	0.80	0.38
58.7	61.5-55.8	20	0.70	0.30
53.0	55.8-50.2	20	0.69	0.27
47.6	50.2-44.9	20	0.65	0.23
42.5	44.9-40.0	20	0.60	0.19
37.7	40.0-35.4	20	0.56	0.16
33.2	35.4-31.0	20	0.54	0.13
29.0	31.0-26.9	20	0.50	0.11
25.0	26.9-23.0	20	0.48	0.09
21.2	23.0-19.3	20	0.45	0.07
17.7	19.3-16.1	20	0.39	0.05
14.5	16.1-13.0	20	0.38	0.04
11.6	13.0-10.3	20	0.33	0.03
8.6	10.3- 7.0	20	0.40	0.03
6.4	7.0- 5.9	20	0.13	0.01
4.9	5.9- 4.0	20	0.23	0.01
3.2	4.0- 2.5	20	0.18	0.00
2.0	2.5- 1.4	20	0.13	0.00
1.0	1.4- 0.5	20	0.11	0.00
66.4	70.0-62.7	20	0.89	0.44
59.6	62.7-56.5	20	0.76	0.33
53.6	56.5-50.7	20	0.71	0.28
47.8	50.7-45.0	20	0.70	0.25
42.3	45.0-39.6	20	0.66	0.21
37.1	39.6-34.6	20	0.61	0.17
32.3	34.6-30.0	20	0.56	0.13
27.8	30.0-25.6	20	0.54	0.11
23.5	25.6-21.5	20	0.50	0.09
19.7	21.5-17.9	20	0.44	0.06
16.2	17.9-14.6	20	0.40	0.05
13.2	14.6-11.8	20	0.34	0.03

NOMINAL SPEED MPH	COAST DOWN SPEED MPH	C.D. TIME SEC	FRICTION TORQ FT-LB	HP
10.5	11.8- 9.2	20	0.32	0.02
8.1	9.2- 7.0	20	0.27	0.02
6.0	7.0- 5.0	20	0.24	0.01
4.2	5.0- 3.3	20	0.21	0.01
2.6	3.3- 1.9	20	0.17	0.00
1.4	1.9- 0.9	20	0.12	0.00
0.5	0.9- 0.2	20	0.09	0.00
66.1	69.8-62.3	20	0.92	0.45
59.2	62.3-56.1	20	0.76	0.33
53.1	56.1-50.1	20	0.73	0.29
47.3	50.1-44.5	20	0.69	0.24
42.0	44.5-39.4	20	0.62	0.19
36.9	39.4-34.4	20	0.61	0.17
32.1	34.4-29.7	20	0.58	0.14
27.6	29.7-25.5	20	0.51	0.10
23.5	25.5-21.5	20	0.49	0.09
19.7	21.5-17.9	20	0.44	0.06
16.2	17.9-14.6	20	0.40	0.05
13.1	14.6-11.6	20	0.37	0.04
10.4	11.6- 9.1	20	0.31	0.02
7.9	9.1- 6.7	20	0.29	0.02
5.7	6.7- 4.6	20	0.26	0.01
3.8	4.6- 3.0	20	0.20	0.01
2.3	3.0- 1.6	20	0.17	0.00
1.2	1.6- 0.7	20	0.11	0.00
0.4	0.7- 0.0	20	0.09	0.00

RUN
JM14R

CLAYTON DYNAMOMETER FRICTION STUDY

REAR ROLLS - CELL NUMBER 14
TEST DATE: JUNE 16, 1976

NOMINAL SPEED MPH	COAST DOWN SPEED MPH	C.D. TIME SEC	FRICTION TORQ FT-LB	HP
67.6	70.1-65.0	30	0.42	0.21
62.1	65.0-59.1	30	0.48	0.22
56.5	59.1-53.9	30	0.42	0.18
51.4	53.9-48.8	30	0.42	0.16
46.2	48.8-43.5	30	0.43	0.15
41.1	43.5-38.6	30	0.40	0.12
36.2	38.6-33.7	30	0.40	0.11
31.1	33.7-28.6	30	0.42	0.10
26.0	28.6-23.5	30	0.42	0.08
20.7	23.5-17.8	30	0.46	0.07
14.9	17.8-12.0	30	0.47	0.05
8.9	12.0- 5.8	30	0.51	0.03
65.2	68.0-62.3	30	0.46	0.22
59.7	62.3-57.0	30	0.43	0.19
54.6	57.0-52.2	30	0.39	0.16
49.8	52.2-47.5	30	0.38	0.14
45.1	47.5-42.7	30	0.39	0.13
40.5	42.7-38.3	30	0.36	0.11
36.1	38.3-33.8	30	0.37	0.10
31.6	33.8-29.4	30	0.36	0.08
27.2	29.4-25.0	30	0.36	0.07
22.6	25.0-20.2	30	0.39	0.07
17.7	20.2-15.1	30	0.42	0.05
12.5	15.1- 9.9	30	0.42	0.04
7.2	9.9- 4.5	30	0.44	0.02

DONE

RUN
JM16R

CLAYTON DYNAMOMETER FRICTION STUDY

REAR ROLLS - CELL NUMBER 16
TEST DATE: JUNE 19,1976

NOMINAL SPEED MPH	COAST DOWN SPEED MPH	C.D. TIME SEC	FRICTION TORQ FT-LB	HP
63.9	70.1-57.7	30	1.01	0.48
52.1	57.7-46.5	30	0.91	0.35
41.5	46.5-36.5	30	0.82	0.25
31.9	36.5-27.3	30	0.75	0.18
23.0	27.3-18.7	30	0.70	0.12
15.0	18.7-11.2	30	0.61	0.07
8.1	11.2- 5.0	30	0.51	0.03
2.9	5.0- 0.9	30	0.33	0.01
62.5	68.8-56.1	30	1.04	0.48
51.0	56.1-45.9	30	0.83	0.31
40.3	45.9-34.7	30	0.91	0.27
30.1	34.7-25.5	30	0.75	0.17
21.2	25.5-16.9	30	0.70	0.11
13.3	16.9- 9.6	30	0.60	0.06
6.7	9.6- 3.7	30	0.48	0.02
2.0	3.7- 0.3	30	0.28	0.00
57.7	63.7-51.7	30	0.98	0.42
46.3	51.7-40.9	30	0.88	0.30
36.0	40.9-31.1	30	0.80	0.21
26.7	31.1-22.2	30	0.72	0.14
18.2	22.2-14.2	30	0.65	0.09
10.9	14.2- 7.6	30	0.54	0.04
5.0	7.6- 2.4	30	0.42	0.02

DONE

RUN
JM28R

CLAYTON DYNAMOMETER FRICTION STUDY

REAR ROLLS - CELL NUMBER 28
TEST DATE: JUNE 4, 1976

NOMINAL SPEED MPH	COAST DOWN SPEED MPH	C.D. TIME SEC	FRICTION TORQ FT-LB	HP
64.6	70.7-58.5	20	1.49	0.71
53.0	58.5-47.5	20	1.35	0.53
42.5	47.5-37.4	20	1.24	0.39
32.8	37.4-28.3	20	1.11	0.27
24.2	28.3-20.0	20	1.02	0.18
16.2	20.0-12.5	20	0.92	0.11
9.5	12.5- 6.4	20	0.75	0.05
4.2	6.4- 2.0	20	0.54	0.02
63.3	69.1-57.5	20	1.42	0.66
52.2	57.5-47.0	20	1.28	0.50
42.2	47.0-37.3	20	1.19	0.37
32.8	37.3-28.3	20	1.10	0.27
24.2	28.3-20.2	20	0.99	0.18
16.5	20.2-12.7	20	0.92	0.11
9.7	12.7- 6.6	20	0.75	0.05
4.4	6.6- 2.1	20	0.55	0.02
66.9	73.3-60.6	20	1.55	0.77
55.0	60.6-49.3	20	1.38	0.56
44.2	49.3-39.0	20	1.26	0.41
34.2	39.0-29.5	20	1.16	0.29
25.2	29.5-20.9	20	1.05	0.20
17.0	20.9-13.1	20	0.95	0.12
10.0	13.1- 6.8	20	0.77	0.06
4.4	6.8- 2.1	20	0.58	0.02
62.8	69.0-56.7	20	1.50	0.70
51.1	56.7-45.5	20	1.37	0.52
40.4	45.5-35.3	20	1.25	0.37
30.7	35.3-26.0	20	1.14	0.26
21.7	26.0-17.5	20	1.04	0.17
13.9	17.5-10.3	20	0.88	0.09
7.4	10.3- 4.5	20	0.71	0.04
2.6	4.5- 0.7	20	0.46	0.01
66.8	72.5-61.1	20	1.39	0.69
56.0	61.1-50.9	20	1.25	0.52
46.1	50.9-41.3	20	1.17	0.40
36.8	41.3-32.3	20	1.10	0.30
28.2	32.3-24.1	20	1.00	0.21
20.2	24.1-16.4	20	0.94	0.14
13.1	16.4- 9.7	20	0.82	0.08
7.0	9.7- 4.3	20	0.66	0.03
2.5	4.3- 0.7	20	0.44	0.01

DONE
SCR

RUN
JM29R

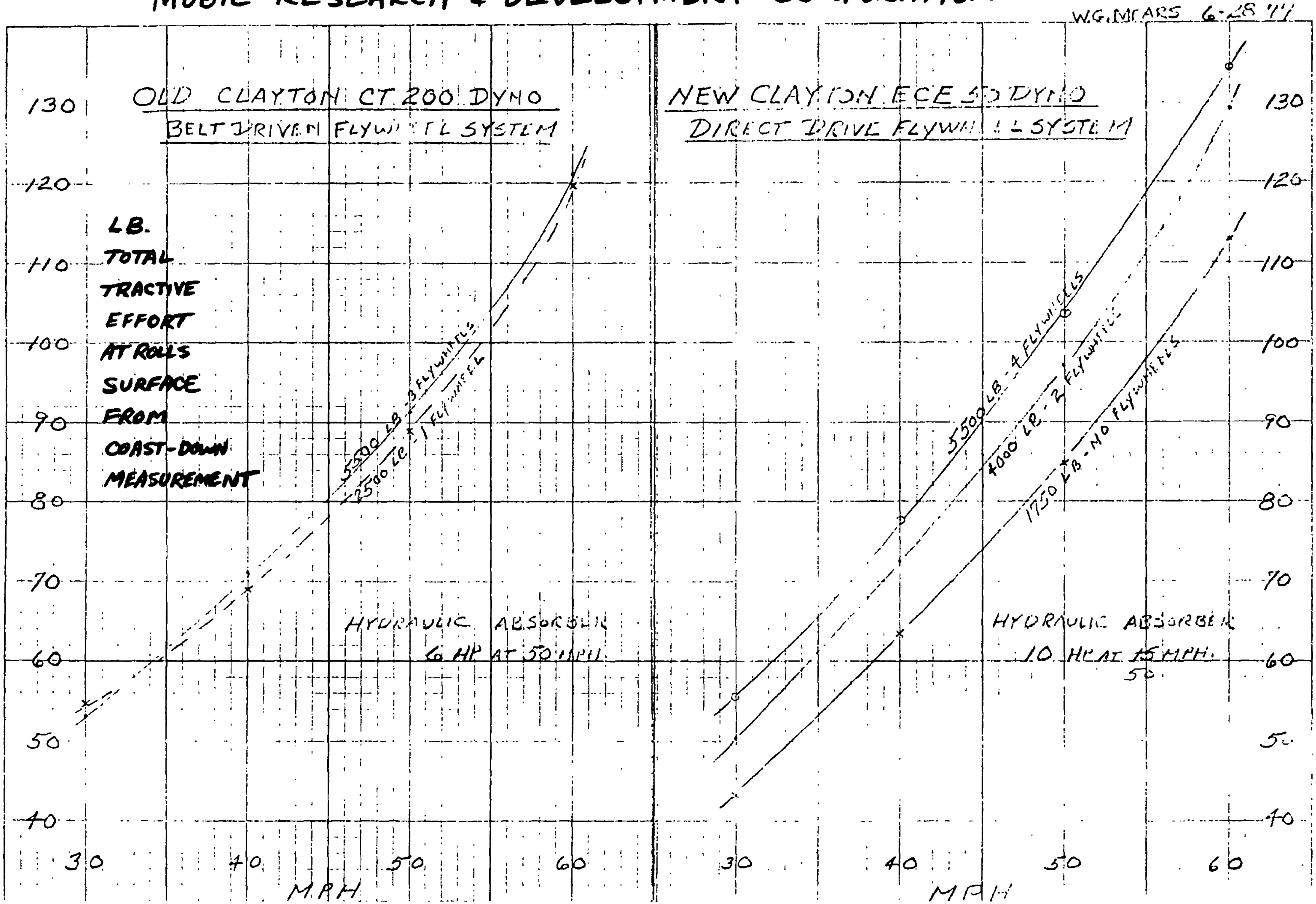
CLAYTON DYNAMOMETER FRICTION STUDY

REAR ROLLS - CELL NUMBER 29
TEST DATE: MAY 27, 1976

NOMINAL SPEED MPH	COAST DOWN SPEED MPH	C.D. TIME SEC	FRICTION TORQ FT-LB	HP
59.8	65.7-53.9	30	0.96	0.43
49.3	53.9-44.7	30	0.75	0.27
40.7	44.7-36.7	30	0.65	0.20
33.1	36.7-29.5	30	0.59	0.14
26.3	29.5-23.1	30	0.52	0.10
20.2	23.1-17.3	30	0.47	0.07
14.8	17.3-12.3	30	0.41	0.04
10.1	12.3- 8.0	30	0.35	0.03
6.2	8.0- 4.5	30	0.29	0.01
59.1	64.3-53.8	30	0.86	0.37
49.5	53.8-45.1	30	0.71	0.26
41.3	45.1-37.5	30	0.62	0.19
34.0	37.5-30.5	30	0.57	0.14
27.5	30.5-24.4	30	0.50	0.10
21.7	24.4-18.9	30	0.45	0.07
16.5	18.9-14.1	30	0.39	0.05
12.0	14.1- 9.9	30	0.34	0.03
8.1	9.9- 6.4	30	0.29	0.02
5.1	6.4- 3.7	30	0.22	0.01
2.7	3.7- 1.7	30	0.16	0.00
1.0	1.7- 0.3	30	0.11	0.00
62.4	67.7-57.1	30	0.86	0.40
52.8	57.1-48.6	30	0.69	0.27
44.8	48.6-41.0	30	0.62	0.21
37.6	41.0-34.2	30	0.55	0.15
31.1	34.2-28.1	30	0.50	0.11
25.3	28.1-22.6	30	0.45	0.08
20.1	22.6-17.6	30	0.41	0.06
15.4	17.6-13.1	30	0.37	0.04
11.2	13.1- 9.3	30	0.31	0.03
7.7	9.3- 6.1	30	0.26	0.01
4.8	6.1- 3.5	30	0.21	0.01
2.6	3.5- 1.6	30	0.15	0.00
0.9	1.6- 0.2	30	0.11	0.00
55.8	60.4-51.2	30	0.75	0.31
47.2	51.2-43.3	30	0.64	0.23
39.7	43.3-36.1	30	0.59	0.17
32.9	36.1-29.7	30	0.52	0.13
26.7	29.7-23.8	30	0.48	0.10
21.2	23.8-18.5	30	0.43	0.07
16.2	18.5-13.8	30	0.38	0.05
11.7	13.8- 9.6	30	0.34	0.03
8.0	9.6- 6.3	30	0.27	0.02
4.9	6.3- 3.6	30	0.22	0.01
2.6	3.6- 1.6	30	0.16	0.00
0.8	1.6- 0.1	30	0.12	0.00

NOMINAL SPEED MPH	COAST DOWN SPEED MPH	C.D. TIME SEC	FRICTION TORQ FT-LB	HP
67.2	73.0-61.3	30	0.95	0.47
56.5	61.3-51.7	30	0.78	0.33
47.7	51.7-43.7	30	0.65	0.23
40.1	43.7-36.5	30	0.59	0.17
33.2	36.5-30.0	30	0.53	0.13
27.0	30.0-24.1	30	0.48	0.10
21.4	24.1-18.7	30	0.44	0.07
16.4	18.7-14.1	30	0.38	0.05
12.1	14.1-10.1	30	0.33	0.03
8.4	10.1- 6.6	30	0.29	0.02
5.2	6.6- 3.8	30	0.23	0.01
2.7	3.8- 1.7	30	0.17	0.00
1.0	1.7- 0.3	30	0.11	0.00

SUBMITTED BY BILL MEARS 6/29/77
MOBIL RESEARCH & DEVELOPMENT CORPORATION



CO-225 (5-71) 5

MOBIL RESEARCH AND DEVELOPMENT CORPORATION

ENGINEERING DEPARTMENT

FOR: SCHEMATIC CLAYTON

LOCATION: FLYWHEEL SYSTEMS

SUBJECT:

JOB No.

PAGE

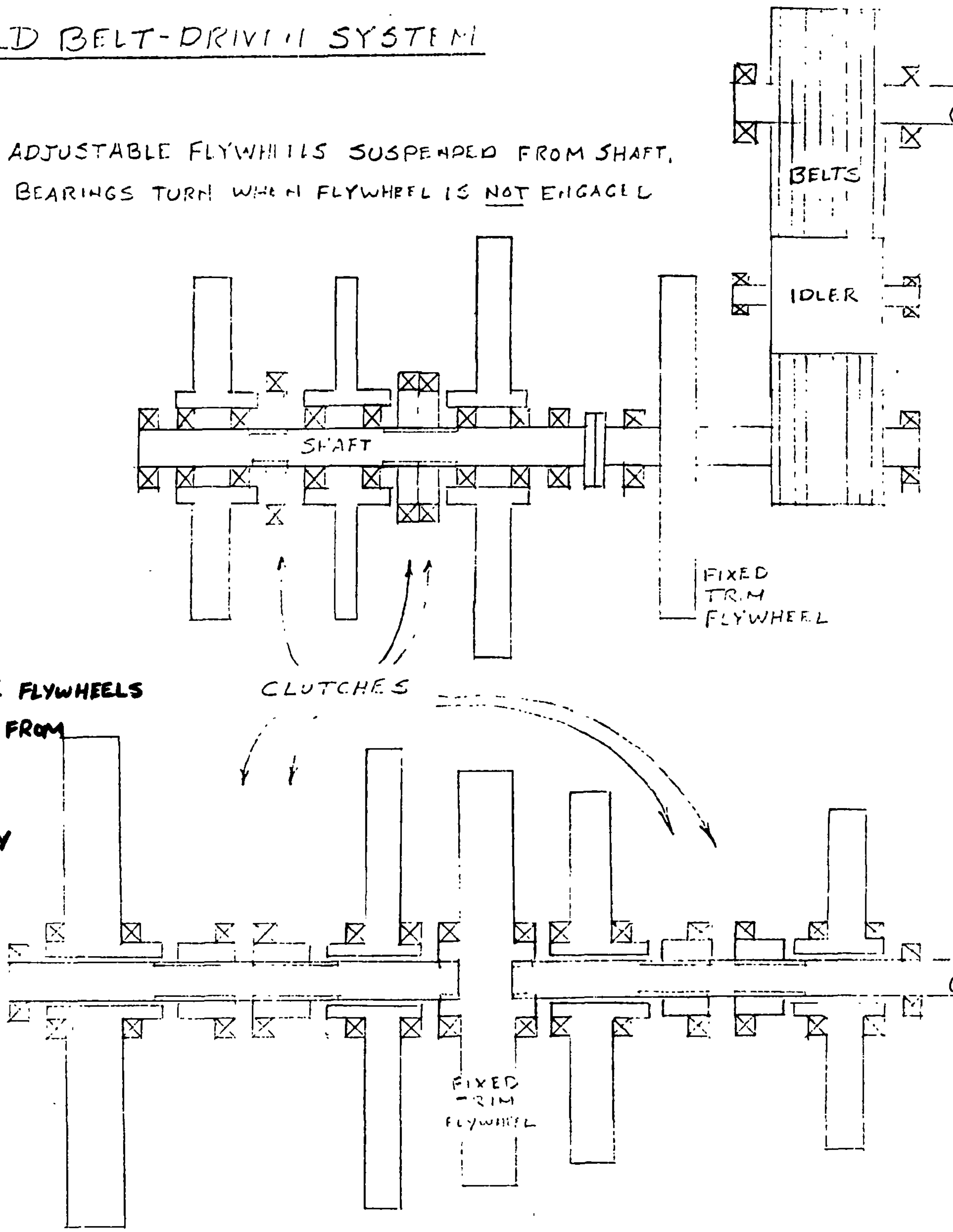
DATE: 6-28-77

BY: W. J. [signature]

REFERENCE

OLD BELT-DRIVEN SYSTEM

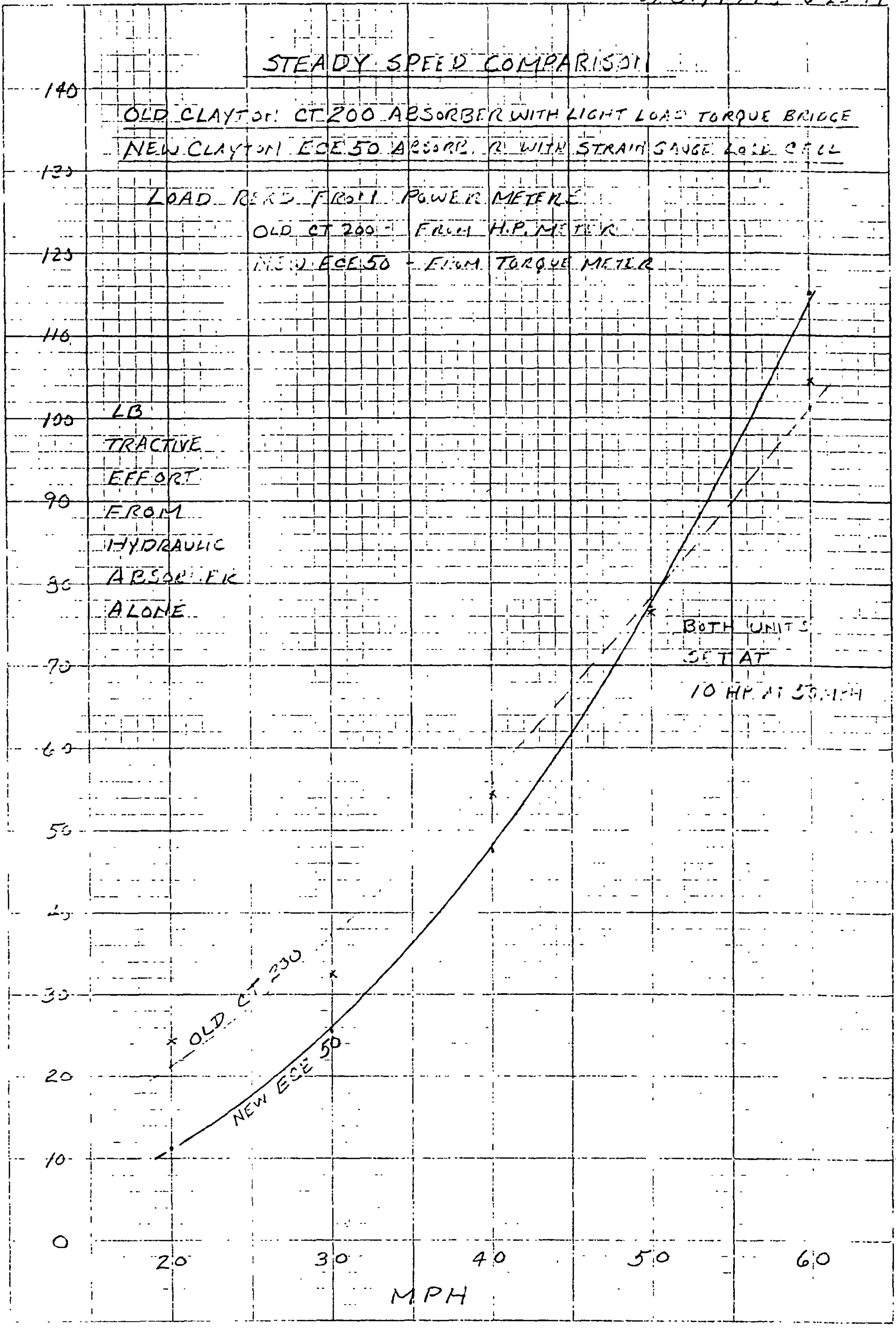
ADJUSTABLE FLYWHEELS SUSPENDED FROM SHAFT.
BEARINGS TURN WHEN FLYWHEEL IS NOT ENGAGED



ADJUSTABLE FLYWHEELS SUSPENDED FROM FRAME. BEARINGS TURN ONLY WHEN FLYWHEEL IS ENGAGED

NEW DIRECT DRIVE SYSTEM

W. G. MEARS 6-23-77



CO-225 (5-71)

MOBIL RESEARCH AND DEVELOPMENT CORPORATION

ENGINEERING DEPARTMENT

FOR CLAYTON DYNO FRICTION CALIBRATION JOB No.

LOCATION OLD CT200 WITH BELT DRIVEN FLYWHEELS, PAGE

SUBJECT APPROX EQUIV. WT. REAR ROLLS; 84 LB. DATE DATA 11-5-73

COASTDOWN DATA BY [illegible] 6-28-77

REFERENCE

ALL DATA TAKEN WITH HYDRAULIC ABSORBER AT 6 HP AT 50 MPH.

TOTAL EQUIV VEHICLE WT. LB.	SECONDS FOR 10 MPH SPEED DECREASE	AVG MPH FOR DECEL TIME	TOTAL DECEL FORCE, LB.	FLYWHEELS ENGAGED		
				500	1000	2000
5500	20.4	60	120.96	✓	✓	✓
	27.0	50	91.39			
	34.8	40	70.91			
	46.3	30	53.29			
4000	14.5	60	123.04			✓
	19.8	50	90.11			
	24.6	40	71.94			
	32.0	30	55.75			
3000	10.6	60	125.33		✓	
	14.1	50	94.22			
	18.2	40	73.00			
	24.0	30	55.36			
2500	9.2	60	119.64	✓		
	12.4	50	88.77			
	16.0	40	68.86			
	20.0	30	55.04			
2000	7.9	60	110.50	NONE		
	9.9	50	88.17			
	12.3	40	70.97			
	15.8	30	55.24			

CO-225 (5-71)

MOBIL RESEARCH AND DEVELOPMENT CORPORATION
ENGINEERING DEPARTMENT

FOR CLAYTON DYNO FRICTION CALIBRATION JOB No. ____

LOCATION NEW ECE 50 WITH DIRECT DRIVE PAGE 1

SUBJECT FLYWHEEL. APPROX EQUIV. WT. REAR ROLLS, 140 LB, COASTDOWN DATA

DATE DATA 3-4-75

BY [illegible] 6-8-77

REFERENCE

EQUIV. WT. TOTAL LB	SECONDS FOR Δ 10 MPH	AVG MPH FOR Δ	HYDRAULIC ABSORBER HP AT 50 MPH	TOTAL DECEL FORCE, LB	FLYWHEELS ENGAGED 250	500	1000	2000
1750	6.5	60	10.0	112.85	NONE			
	8.5	50		86.35				
	11.3	40		64.91				
	16.7	30		43.92				
	6.5	60		112.85				
	8.8	50		83.35				
	11.7	40		62.69				
	17.3	30		42.40				
5500	18.2	60		134.18	✓	✓	✓	✓
	23.5	50		103.7[illegible]				
	31.3	40		78.03				
	43.8	30		55.75				
	18.2	60		134.15				
	23.6	50		103.48				
	31.5	40		77.5[illegible]				
	44.0	30		55.50				
2000	6.9	60	10.5	122.81	✓			
	9.1	50		93.12				
	12.1	40		70.03				
	17.6	30		48.15				
2250	7.9	60		121.69		✓		
	10.3	50		93.3[illegible]				
	13.7	40		70.17				
	19.3	30		49.51				
2750	9.4	60	10.9	126.50			✓	
	12.2	50		97.47				
	16.[illegible]	40		73.40				
	23.4	30		50.92				

CO-225 (5-71)

MOBIL RESEARCH AND DEVELOPMENT CORPORATION

ENGINEERING DEPARTMENT

FOR CLAYTON DYNO FRICTION CALIBRATION — JOB No. ____

LOCATION NEW ECE 50 WITH DIRECT DRIVE — PAGE 2

SUBJECT FLYWHEEL. APPROX EQUIV. WT. REAR ROLLS, 140 LB, COASTDOWN DATA — DATE DATA 3-4-75

BY [illegible] 6-28-77
REFERENCE

EQUIV. WT. TOTAL LB	SECONDS FOR Δ 10 MPH	AVG MPH FOR Δ	HYDRAULIC ABSORBER HP AT 50 MPH	TOTAL DECEL FORCE, LB	FLYWHEELS ENGAGED 250	500	1000	2000
4000	13.2	60	11.1	133.[illegible]	✓			✓
	17.2	50		102.25				
	22.8	40		77.13				
	32.1	30		54.79				
	49.2	60	1.25	35.74				
	61.5	50		28.60				
	77.1	40		22.81				
	95.7	30		18.35				
	23.1	60	5.0	76.13				
	30.9	50		56.91				
	41.3	40		42.55				
	58.0	30		30.32				
	14.0	60	10.6	125.[illegible]				
	19.0	50		92.56				
	25.8	40		68.16				
	37.4	30		47.02				
	9.8	60	15.0	179.45				
	12.5	[illegible]		[illegible]				
	19.1	[illegible]		92.07				
	29.0	30		60.[illegible]				
	7.9	60	20.1	222.[illegible]				
	[illegible]	[illegible]		161.34				
	[illegible]	[illegible]		115.70				
	[illegible]	30		74.5[illegible]				
	8.4	60	25.[illegible]	209.[illegible]				
	12.[illegible]	4[illegible]		146.55				
	19.[illegible]	[illegible]		92.[illegible]				
	14.[illegible]	60	10.0	125.62				
	18.5	[illegible]		95.06				
	25.[illegible]	40		69.79				
	37.0	30		47.53				

CO-228 (8-71)

MOBIL RESEARCH AND DEVELOPMENT CORPORATION

ENGINEERING DEPARTMENT

FOR CLAYTON DYNO FRICTION CALIBRATION — JOB No. ____

LOCATION NEW ECE 50 WITH DIRECT DRIVE — PAGE 3

SUBJECT FLYWHEEL, APPROX EQUIV. WT. REAR ROLLS, 140 LB, COASTDOWN DATA — DATE DATA 3-4-75

BY [illegible] — REFERENCE [illegible]

EQUIV. WT. TOTAL LB	SECONDS FOR Δ 10 MPH	AVG MPH FOR Δ	HYDRAULIC ABSORBER HP AT 50 MPH	TOTAL DECEL FORCE, LB	FLYWHEELS ENGAGED 250	500	1000	2000
5500	17.5	60	10.4	139.54	✓	✓	✓	✓
	23.3	50		104.51				
	31.1	40		78.52				
	44.5	30		54.85				
4000	13.1	60	10.6	134.25	✓			✓
	17.8	50		98.80				
	23.5	40		73.59				
	34.6	30		50.53				
1750	5.5	60	11.0	126.47	NONE			
	7.9	50		92.85				
	10.7	40		65.[illegible]				
	15.7	30		46.72				

CO-225 (5-71)

MOBIL RESEARCH AND DEVELOPMENT CORPORATION

ENGINEERING DEPARTMENT

FOR CLAYTON CT 200 DYNO WITH
JOB No.
LOCATION LOW POWER TORQUE [illegible]
PAGE
SUBJECT POWER ABSORPTION UNIT
DATE 6-28-77
LOADING CHARACTERISTICS 8 5/8" DIA ROLLS
BY [illegible]
REFERENCE

MPH	HP, DECREASE LOAD ↓	↓	HP INCREASE LOAD ↑	↑	AVG HP	LB EQUIV TRACT. EFFORT
70	25.6		24.6		25.1	134.46
60	16.9	16.9	16.5	16.4	16.675	104.22
50	10.3	10.3	10.1	10.1	10.2	76.50
40	6.0	6.0	5.7	5.4	5.775	54.14
30	3.0	2.7	2.3	2.3	2.575	32.19
20	1.5		1.1		1.3	24.38

DATA TAKEN
10-30-73
STEADY STATE

PAU CHARACTERISTIC CURVE
TRACT. EFFORT LB = CONST × $(MPH)^b$
& CORRELATION COEFFICIENT r

CONST = 0.3069
b = 1.416
r^2 = 0.976
} FOR 70 → 20 MPH

CONST = 0.3716
b = 1.359
r^2 = 0.969
} FOR 60 → 20 MPH

CO 225 (5-71)

MOBIL RESEARCH AND DEVELOPMENT CORPORATION

ENGINEERING DEPARTMENT

FOR: CLAYTON ECL 50 DYNO

LOCATION: POWER ABSORPTION UNIT

SUBJECT: LOADING CHARACTERISTICS 8 5/8" DIA ROLLS

JOB NO.

PAGE

DATE: 6-28-77

BY: W. [illegible]

REFERENCE

HP @ 50 MPH	MPH	LB FT TORQUE ↓ DECR. LOAD	LB FT TORQUE ↑ INCR. LOAD	LB FT AVG TORQUE	LB EQUIV TRACT EFFORT
MIN, 1.5	60	4.0	4.0	4.0	11.13
	50	3.0	3.0	3.0	8.35
	40	2.0	2.0	2.0	5.57
	30	1.5	1.5	1.5	4.17
	20	0.9	1.0	0.95	2.69
5	60	20.5	20.5	20.5	57.09
	50	13.8	13.5	13.5	[illegible]
	40	8.0	8.5	8.25	22.96
	30	4.0	4.5	4.25	11.83
	[illegible]	2.0	[illegible]	2.0	5.57
10	60	41.0	42.0	41.5	115.48
	50	[illegible]	[illegible]	[illegible]	[illegible]
	40	16.5	17.5	17.0	[illegible]
	30	[illegible]	[illegible]	[illegible]	[illegible]
	20	4.0	4.0	4.0	11.13
15	60	[illegible]	59.0	59.0	164.17
	50	[illegible]	40.5	[illegible]	[illegible]
	40	24.0	23.5	[illegible]	65.87
	30	13.5	14.0	13.75	33.26
	20	5.5	5.9	5.7	15.86

PAU CHARACTERISTIC CURVE, TRACT. EFFORT, LB = CONST × $(MPH)^b$ & CORRELATION COEF. r^2

MIN, 1.5 HP: CONST. 0.05164; b = 1.297; r^2 = 0.986

5 HP: CONST = 0.005752; b = 2.139; r^2 = 0.998

10 HP: CONST = 0.01870; b = 2.125; r^2 = 0.99[illegible]6

15 HP: CONST = 0.027[illegible]3; b = 2.127; r^2 = 0.9999

DATA TAKEN 6-29-77
STEADY STATE