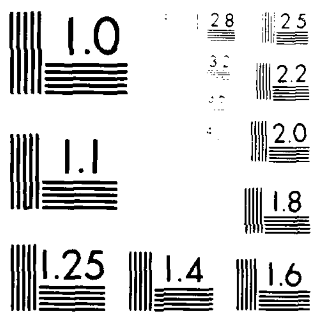
AD-A115 073 AERODYNE DALLAS TX F/G 21/7
TURBOCHARGING OF SMALL INTERNAL COMBUSTION ENGINE AS A MEANS OF--ETC(U)
APR 82 J R ARVIN DAAK70-80-C-0146

UNCLASSIFIED NL

1 OF 1
AD A
115073

END
DATE
FILMED
07-82
DTIC




MICROCOPY RESOLUTION TEST CHART

(12)

AerodyneDallas

AD A115073

FINAL REPORT

CONTRACT NO. DAAK70-80-C-0146

# TURBOCHARGING OF SMALL INTERNAL COMBUSTION ENGINE AS A MEANS OF IMPROVING ENGINE/APPLICATION SYSTEM FUEL ECONOMY— FURTHER TURBOCHARGER IMPROVEMENTS

PREPARED BY


AERODYNE DALLAS
151 REGAL ROW, SUITE 120
DALLAS, TEXAS 75247




82 06 01 233

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

| | |
|---|---|
| 1. REPORT NUMBER | 2. GOVT ACCESSION NO. AD-A115073 |
| 3. RECIPIENT'S CATALOG NUMBER | |
| 4. TITLE (and Subtitle) TURBOCHARGING OF SMALL INTERNAL COMBUSTION ENGINES AS A MEANS OF IMPROVING ENGINE/APPLICATION SYSTEM FUEL ECONOMY-FURTHER TURBOCHARGER IMPROVEMENT. | 5. TYPE OF REPORT & PERIOD COVERED 10/80 - 2/82 |
| | 6. PERFORMING ORG. REPORT NUMBER none |
| 7. AUTHOR(s) John R. Arvin | 8. CONTRACT OR GRANT NUMBER(s) DAAK70-80-C-0146 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Aerodyne Dallas, 151 Regal Row, Suite 120, Dallas, Texas 75247 | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia 22060 | 12. REPORT DATE April 1982 |
| | 13. NUMBER OF PAGES 72 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | 15. SECURITY CLASS. (of this report) UNCLASSIFIED |
| | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE none |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fuel Economy
Turbocharger - diesel engine
Turbocharger - variable turbine geometry
Turbocharger Performance

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Improvements to a small diesel engine turbocharger were made based on data gathered during a previous Army contract. The improved turbocharger was fabricated and tested on a small, four cylinder, 239 CID diesel engine. Engine dynamometer test data revealed a 2 to 9 percent reduction in fuel consumption at all points over the operating envelope.

A turbocharger was operated for 1011 hours at speeds between 70000 and 78000 rpm without incident. The ball bearings were in excellent condition at the

20.

end of the test.

A math model of the engine and turbocharger was generated. The model was used to estimate "13 Mode Federal Diesel Emissions Cycle", the "LA4" driving cycle and the application of the VATN turbocharger to a diesel engine driven generator set. A recommendation was made to build a gen set demo unit. A fuel savings of 8 to 10 percent was estimated for a 30KW DED generator set.

## Summary

Under a previous contract (DAAK70-78-C-0031) a small turbocharger was fabricated and tested on a four cylinder diesel engine. This turbocharger features variable area turbine nozzles, a ball bearing supported rotor and a self-contained lubrication system. Using results from this previous effort, the current contract (DAAK70-80-C-0146) addressed turbocharger improvements, engine testing of the improved turbocharger, bench testing to learn more about the ball bearings and limited bearing durability demonstration, and development of a math model to predict turbocharger and engine operating condition and engine performance.

Turbocharger modification included new compressor and turbine trims which better matched the engine flow requirements. The VATN system was redesigned to give a broader range of turbine flow capacity variation. Additional mods were considered to reduce the heat transfer from turbine to compressor.

The improved turbocharger was instrumented and installed on a diesel engine. Engine dynamometer test data shows a 2 to 9 percent improvement at every operating condition from 40 to 100 percent speed and 25 to 100 percent load at each speed.

Bench testing to define the optimium set of bearing parameters was not completed. A turbocharger was operated 1011 hours at speeds between 70000 and 78000 rpm without incident; this exceeded the contract goal by 300 hours.

A computer math model was created. The model was used to determine improved match between the turbocharger and engine. The model was also used to estimate emissions and BSFC for the "13 Mode Federal Emission Diesel Cycle". Fuel consumption for three diesel engines operating in a VW Rabbit automobile over the LA4 driving cycle was calculated. Fuel consumption improvements of 50 to 64 percent were estimated. A simple VATN control strategy was assessed. Application of the VATN turbocharger to a DED generator set was analyzed. The VATN eliminates turbocharger lag thereby allowing the engine to meet military gen set response requirements. A recommendation was made to replace a six cylinder, N/A diesel with a four cylinder diesel employing a VATN turbocharger. Fuel savings of 8 to 10% were estimated.

# PREFACE

This report was prepared by Aerodyne Dallas under U.S. Army Contract DAAK70-80-C-0146, issued by the Electro-Mechanical Division of the U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, and was under the technical direction of Mr. John R. Arvin.

This report covers the results of the work performed from October 1980 to February 1982, at which time the program was completed.

TABLE OF CONTENTS

## List Of Figures

## List of Tables

# I. INTRODUCTION

Rising fuel costs have put a premium on improving engine fuel efficiency. Turbocharging of internal combustion engines can be used to effect an improvement in fuel economy. This is accomplished largely by down-sizing and/or reducing the rotational speed and turbocharging back to the original, normally aspirated, engine power level. For diesel engines, additional benefits may be realized due to improvements in engine air fuel ratio. As engine size is reduced, turbocharging becomes increasingly difficult. The adverse effects of bearing losses and reduced component efficiencies are magnified in the smaller turbocharger.

Under a previous Army contract, DAAK70-78-C-0031, a turbocharger with several advanced features was built and successfully tested on a John Deere 4239T diesel engine. Engine fuel consumption and emissions were improved over a majority of the operating speed and load range. Even though the previous program was a success, several areas of improvement and further investigation were identified.

These areas included:

- Improved matching of compressor and turbine to engine
- Reduced heat transfer from turbine to compressor
- Improvement to VATN system including airfoil shapes
- Further information about optimum bearing operational parameters
- Substantial extension of engine-turbocharger mathematical model
- Application of mathematical model to estimate 13 mode federal diesel engine cycle, the LA4 cycle, and turbocharger control strategy

The work presented in this final report has been directed toward the above items.

# II. DESIGN MODIFICATIONS AND REMATCHING

Results of previous work had identified several areas where the turbocharger could be improved. A crossection and associated nomenclature are shown in figure 1.

## COMPRESSOR

### Design Modification

An analysis of the previous test data showed that the compressor was operating at 60% efficiency at rated load and speed and at a pressure ratio of 2.0. Therefore, it was decided to increase the compressor flow size 16% and make a vaneless diffuser. A vaneless diffuser will reflect a reduction in peak efficiency but give a broader operating range. There was ample room to provide a vaneless diffuser by machining the vanes from the compressor backwall casting. The diffuser is formed by a converging section followed by a parallel wall section, (see figure 2). The converging section has a radius ratio of 1.432 which provides for substantial reduction in the tangential component of velocity leaving the rotor wheel. The parallel wall portion then diffuses through an area ratio of 1.320. The constant velocity scroll used to collect the flow from the diffuser discharge is unchanged from the original design.

The compressor wheel and diffuser design modifications were made in conjunction with one another. The compressor wheel tip shroud profile was altered to (1) increase the flow capacity 16% above the original design value and (2) reduce the diffusion in the rotor wheel. Also, these changes had to be geometrically consistent with the diffuser inlet. The iterative design process resulted in the aforementioned vaneless diffuser and a new wheel tip shroud contour. The tip shroud profile is $8.6^{\circ}$ from normal at the rotor exit - diffuser inlet. The rotor area ratio was reduced from 1.56 to 1.11.

### Compressor Rig Test

The compressor was tested on the Aerodyne turbocharger test rig. The test equipment is the same as that reported in detail for the previous contract. Basically, The turbine is driven by exhaust gases from a diesel engine which have passed through a settling tank. Diesel engine air flow is measured along with four turbine inlet temperatures, nine turbine exit temperatures, two turbine inlet stagnation pressures (static pressure in settling tank), and three exit static pressures. Compressor measurements include four inlet temperatures, nine exit temperatures, four inlet stagnation pressures, and eight exit stagnation pressures. This data along with turbocharger rotational speed allow detailed component performance to be determined. The compressor operating point is set by adjusting a compressor discharge throttle valve and turbine vane position or diesel engine speed (mass flow to turbine).

FIGURE 1 - AERODYNE TURBOCHARGER CROSSECTION

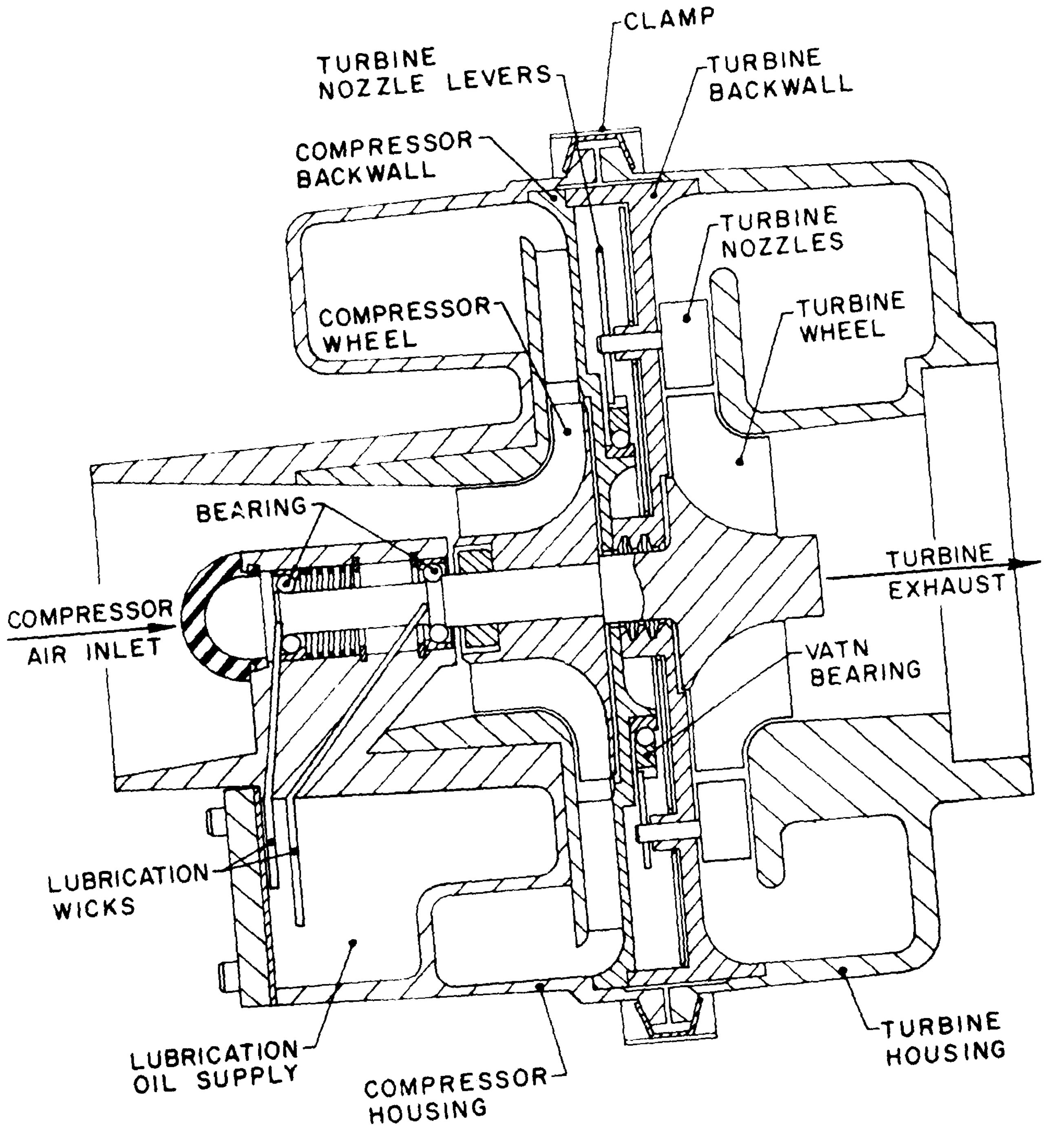


FIGURE 2-COMPRESSOR GEOMETRY MODIFICATIONS

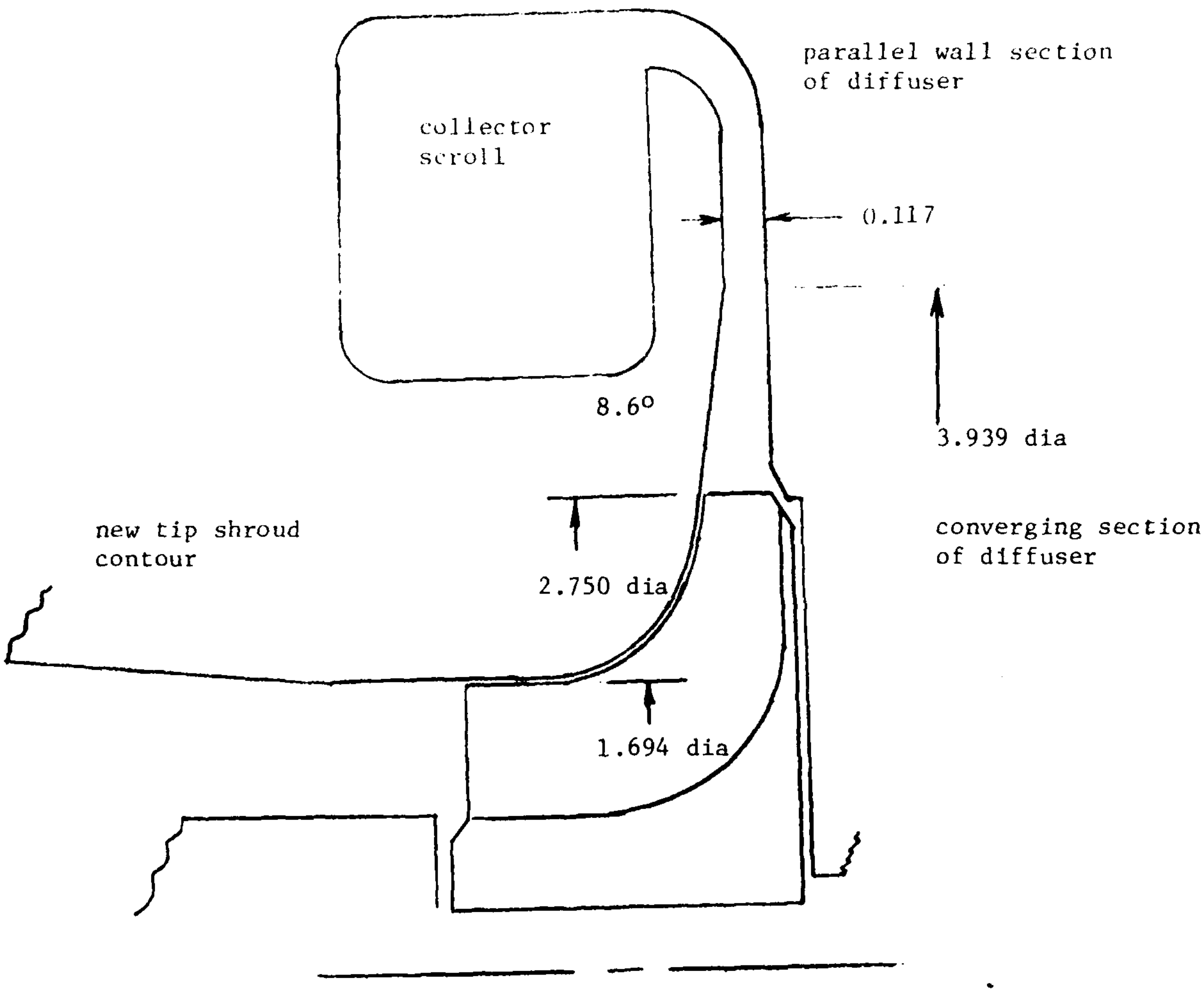
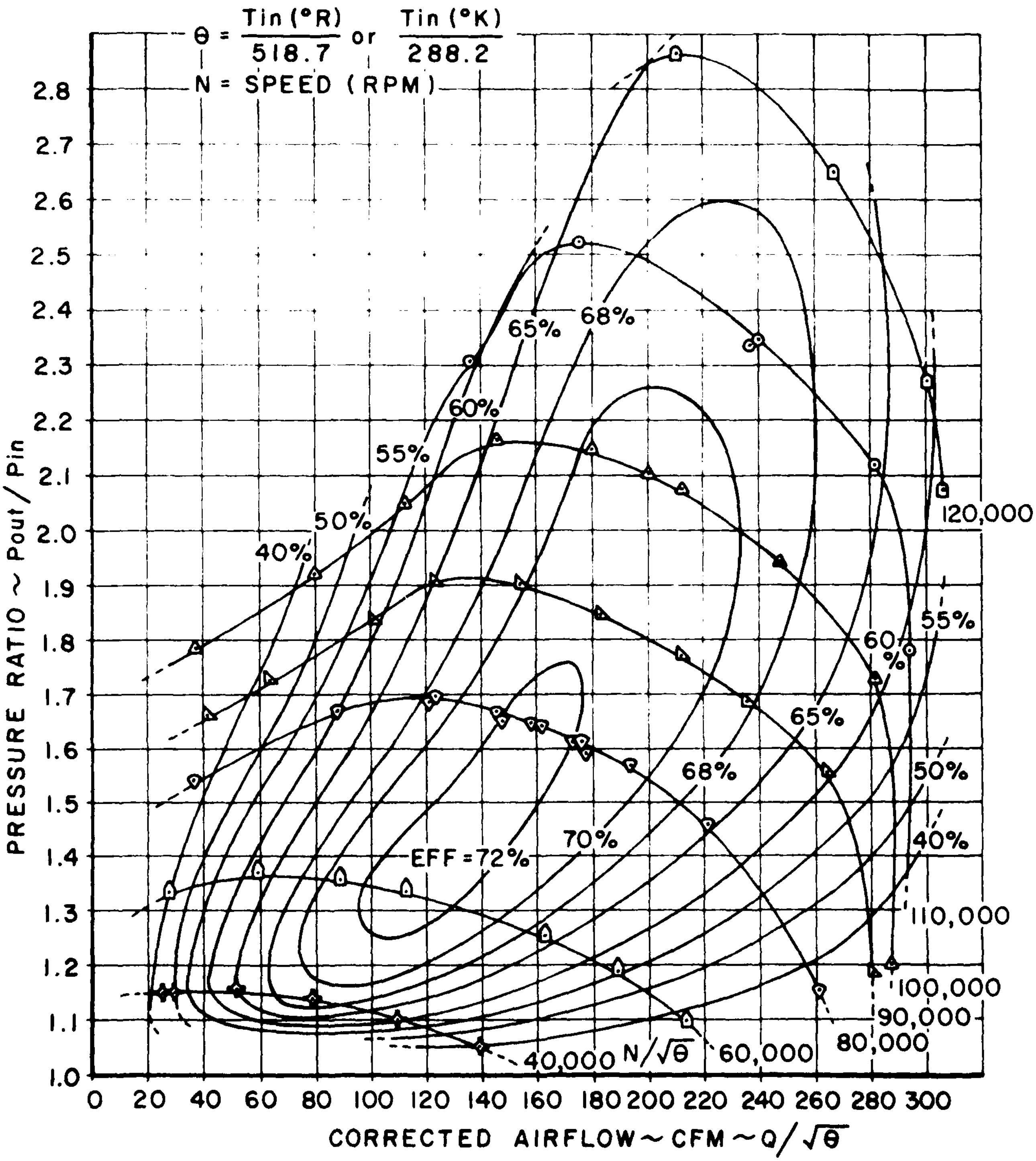


FIGURE 3-

COMPRESSOR MAP



A compressor map was generated from the rig test data which shows compressor efficiency as a function of corrected volumetric flow rate, pressure ratio, and corrected speed, (see figure 3). A peak efficiency of slightly over 72% was measured which is 3 points lower than the original vaned diffuser design. Stable compressor operation was observed even at very low flow rates. At 100000 rpm the lowest corrected flow rate tested was 37 cfm at 1.78 pressure ratio. At the same speed and pressure ratio, the maximum flow was 275 cfm. At flow rates between 37 and 130 cfm, at 100000 rpm, the compressor is in a "soft surge"; but can operate at these conditions indefinitely without damage. Also, the resulting pressurized air is stable.

Heat Transfer

From figure 1 it can be seen that the general arrangement of the turbocharger places the turbine close to the compressor. This leads to heat transfer from the turbine to the compressor. In order to quantify the amount of heat transfer, the process was assumed to be characterized by an "overall heat transfer coefficient" (OAHT) which was defined as the amount of heat transfer (energy per unit time) divided by the difference in temperature between turbine inlet and compressor discharge. To deduce this coefficient, compressor test rig data and turbocharger data from the engine test performed during the previous contract were used. A value for OAHT was determined which resulted in the compressor efficiency calculated from engine data equal to the component test rig value i.e. the compressor map. The compressor rig data was generated with a low turbine inlet temperature, 250°F to 350°F; therefore, the overall heat transfer is minimal. Steps were taken to reduce the heat transfer even before the beginning of the current contract. These mainly included minimizing the area normal to the flow of heat across the outer diameter of the turbine backwall. Figure 4 presents the OAHT as a function of compressor pressure ratio for the original turbocharger test in the previous contract and for the turbocharger as modified since that point in time. The engine tests were conducted at Southwest Research Institute, San Antonio, for the previous contract. The OAHT was reduced frcm .0013 Btu/sec°F. Wall temperature measurements were made at various locations on the turbine and compressor housings. This data along with material conductivities, and estimated heat transfer coefficient were used to calculate the heat flow through several paths via a heat balance.

Four paths were identified as follows:

path 1 - From turbine housing to compressor housing through "V" clamp

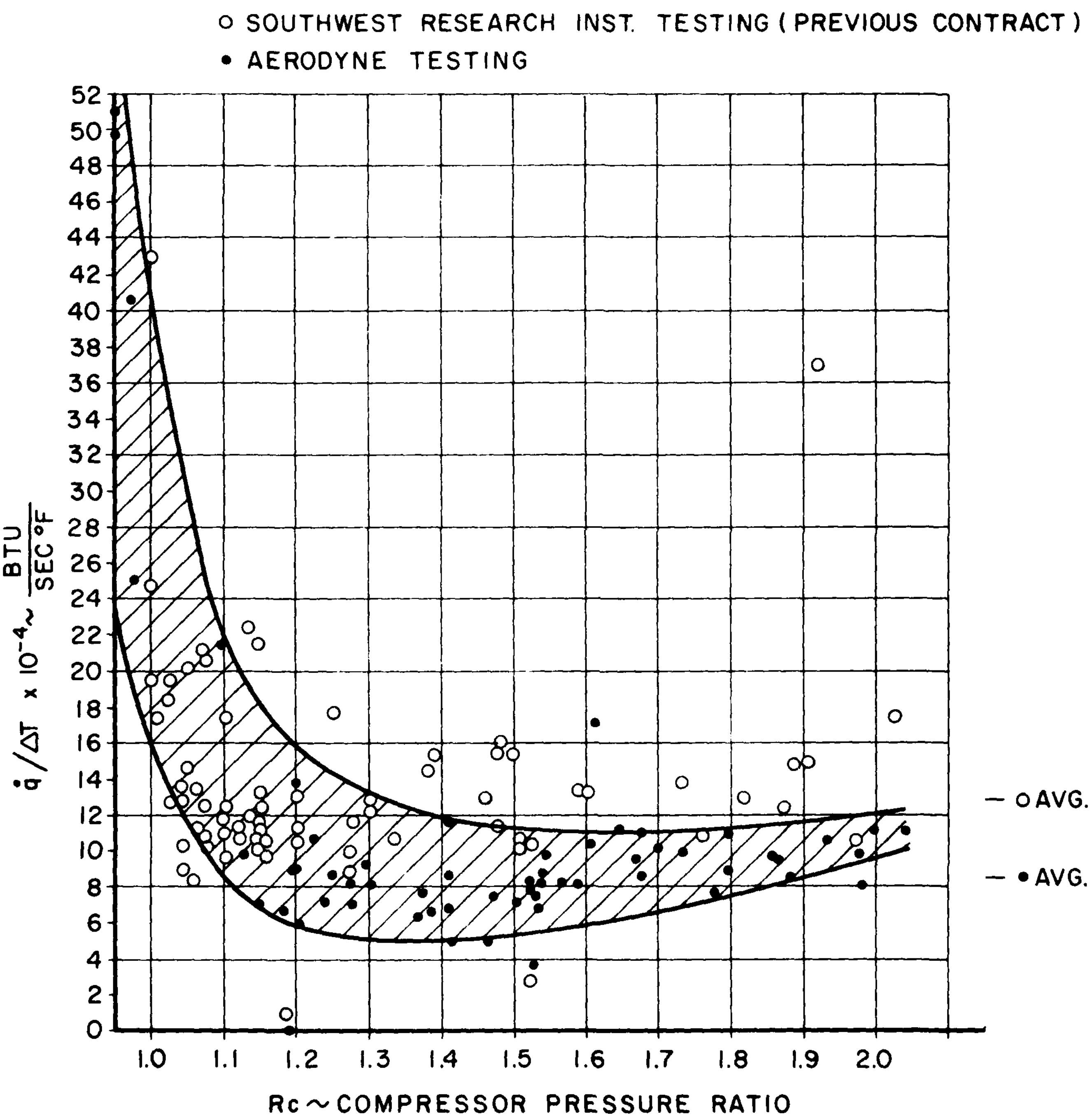
path 2 - From turbine backwall at outer diameter to compressor backwall

path 3 - Across the air gap between backwalls

path 4 - Along shaft from turbine wheel to compressor

FIGURE 4 -

DEDUCED OVERALL HEAT TRANSFER COEFFICIENT



The contribution of each of these four paths was estimated to be in the following proportion after the initial heat transfer mods were made.

path 1 - 27% of total

path 2 - 49% of total

path 3 - 16% of total

path 4 - 8 % of total

Further modifications were considered. These included:

a - Adding another insulator next to the compressor backwall between the VATN bearing and the outer diameter of the compressor backwall.

b - Make a ceramic turbine backwall with the ceramic material properties biased toward low thermal conductivity.

c - Thermal barrier coating the turbine backwall

d - Insulate "V" clamp from housings

e - Additional reductions in area normal to heat flow path 2.

The cost and lead-time for item b were not within the constraints of the current program. Item c was discontinued because of the risk of the thermal barrier coming loose from the backwall. Item d was tried; but the insulating material would not allow the "V" clamp to remain tight thereby allowing leakage.

Items a and e were employed. Item e took on the form of a heat dam (groove) which was machined in the outer ring of the turbine backwall.

TURBINE

VATN Design Modification

The original design allowed for the turbine vanes to be moved $\pm$ 10 degrees from a nominal position. The VATN bearing, which serves as a unison ring, was modified in order that the turbine nozzle vanes could be moved $\pm$ 14 degrees from nominal. The vane air foil shape was redefined. The airfoil chord was reduced from 0.94 to 0.84 inches, (see figure 5). The new airfoil shape not only provides additional clearance between the vane trailing edge and the rotor blade leading edges (at full open vane position); but, also the vane channel convergence was improved. It is aerodynamically desirable to have the channel formed by two adjacent vanes to converage as the gas passes from the inlet to the throat. Figure 6 presents the channel width as a function of distance along the channel for the original vane shape in both the full open and closed positions.

Three new shapes were considered. Figure 7 shows the new vane shape selected. Figure 8 presents the channel convergence of the new design which is much improved as compared to that shown in figure 6 for the original design.

FIGURE 5 -

ORIGINAL DESIGN TURBINE VANE IN CLOSED POSITION

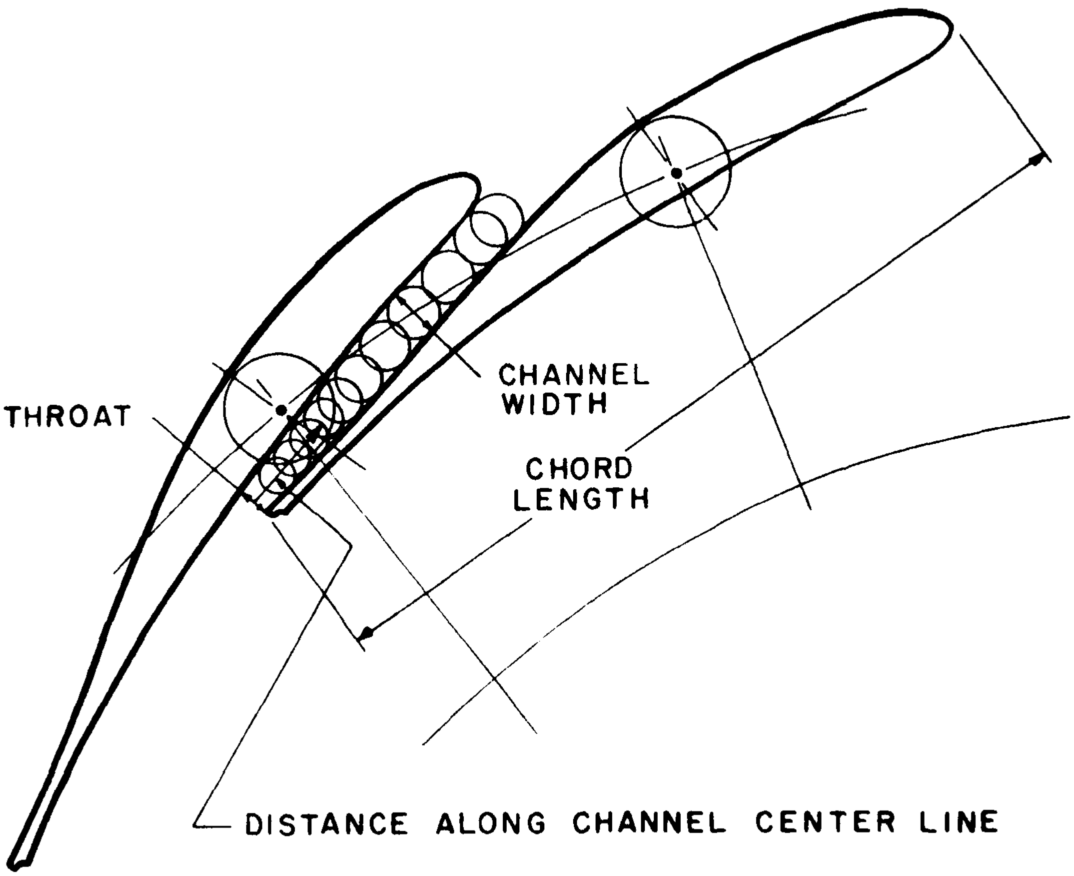


FIGURE 6 -

ORIGINAL DESIGN

TURBINE VANE CHANNEL CONVERGENCE

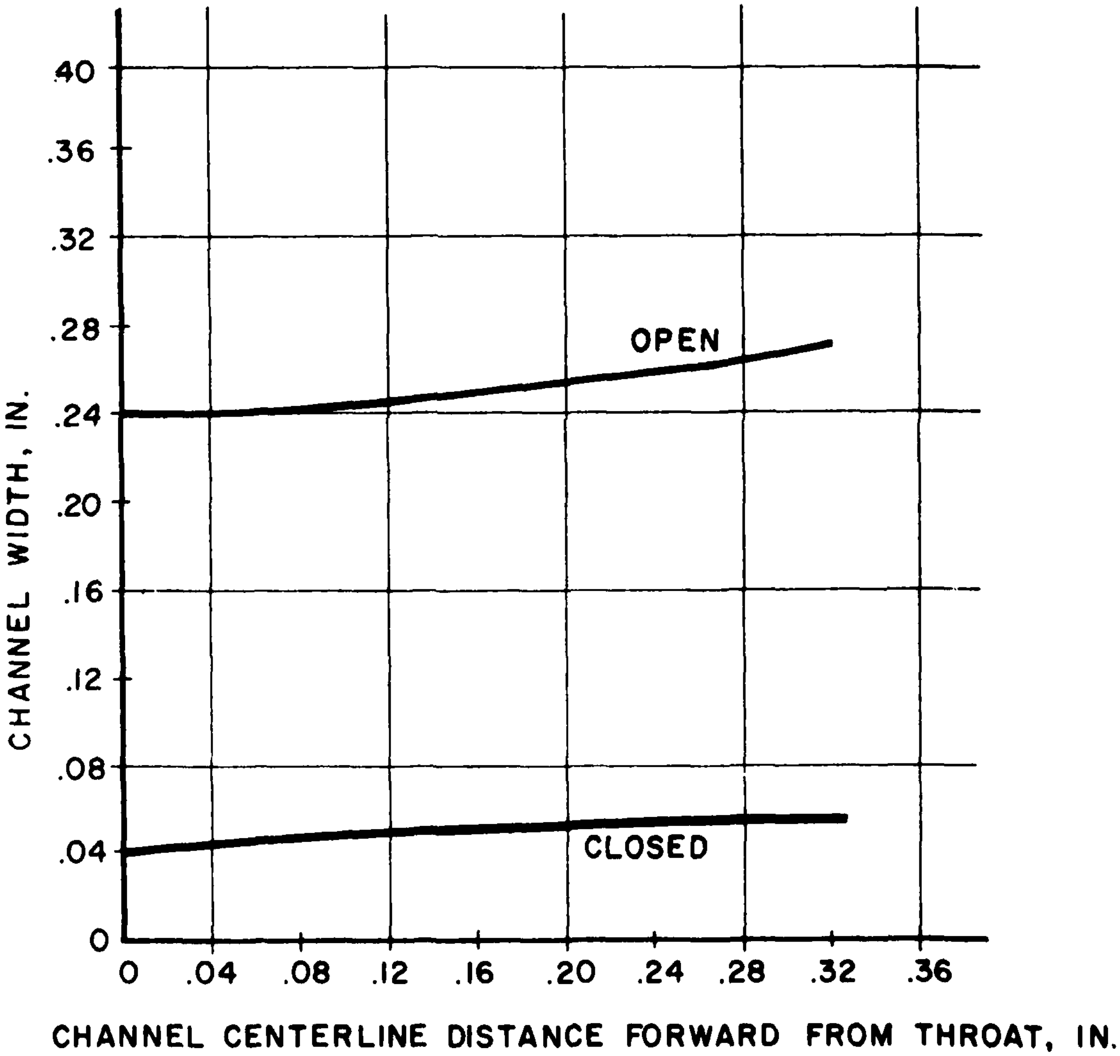


FIGURE 7-

NEW TURBINE VANE SHAPE IN CLOSED POSITION

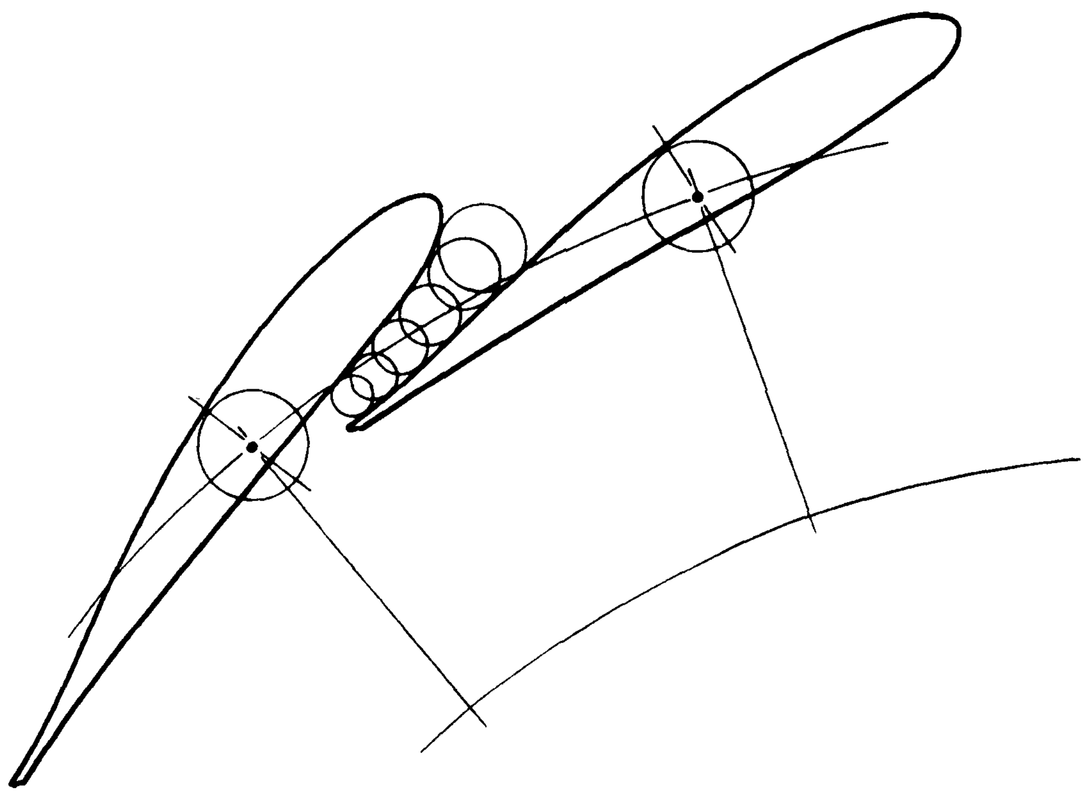
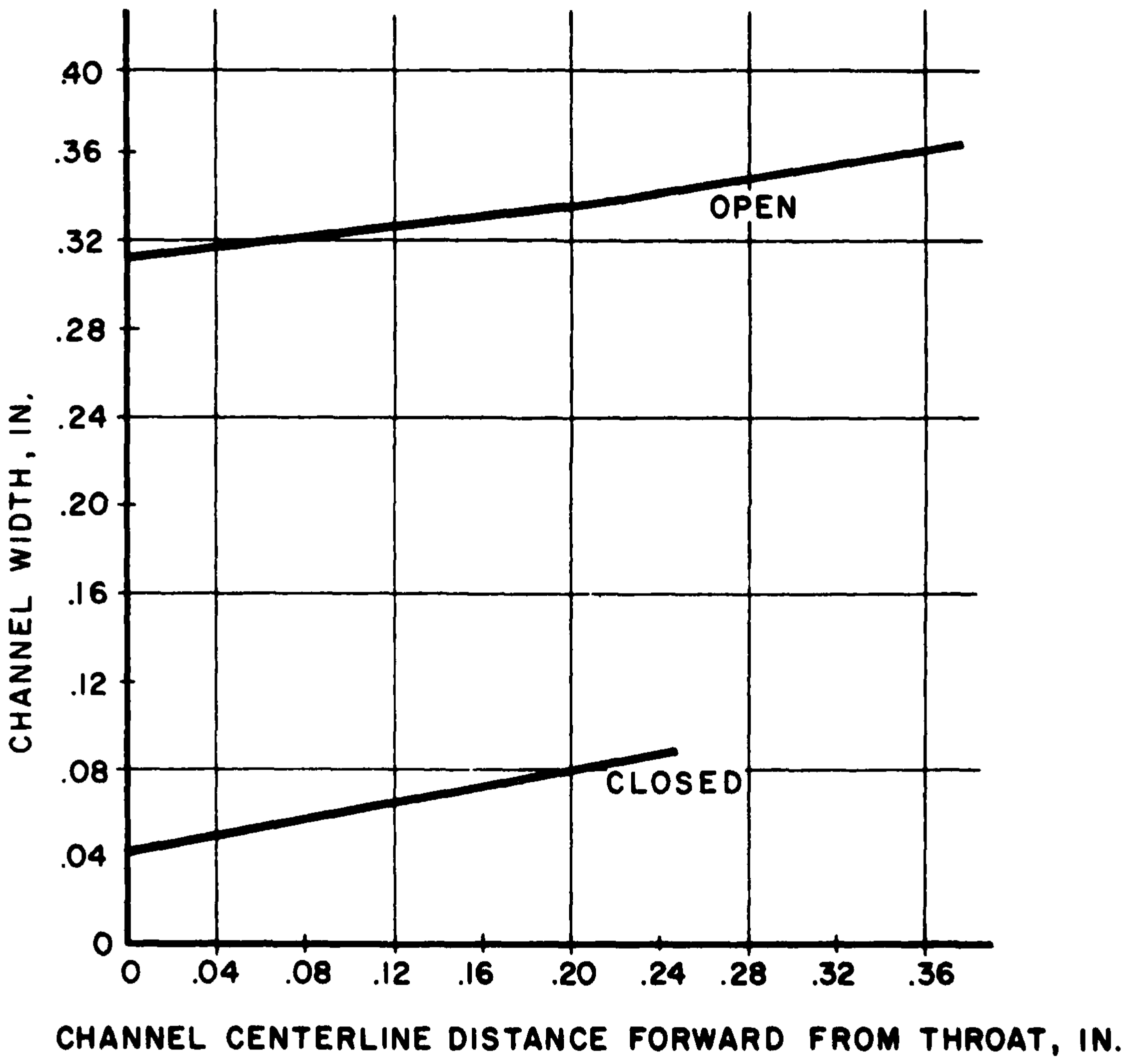


FIGURE 8-

NEW TURBINE VANE CHANNEL CONVERGENCE



## Turbine Size Reduction

The engine to turbocharger matching was assessed via a computerized mathematical model of the turbocharger and engine system. This model was used to determine the change in turbine and compressor trim (flow size) to better match the engine requirements. The new compressor trim was reported in a previous section of this report. The new turbine trim was estimated to be 0.250 rather than 0.370. These numbers are the vane height (and rotor blade inlet height) in inches. Consideration was given to 0.200 turbine but rig tests showed that an efficiency loss of 3 to 13 percent may offset the reduced size benefits. Therefore, the 0.250 turbine was selected.

## III. ENGINE TESTING

The new design changes were incorporated and two model 2.66I/D turbochargers were built for testing on the John Deere 4239T diesel engine. One turbocharger was used for bench testing the other for the engine tests.

The purpose of the engine testing was to demonstrate the improved engine fuel consumption with the VATN turbocharger as compared to the original, bill of materials turbocharger, an Airesearch T04.

### TEST FACILITY AND INSTRUMENTATION

All testing was conducted at Aerodyne Dallas, Dallas, Texas. The engine tests were performed on a Midwest type MW1014A eddy current, engine dynamometer. The dynamometer is controlled with a Digalog electronic controller. The Hewlett Packard 3052A Automatic Data Acquisition System, which services the turbocharger test rig and was described in the DAAK70-78-C-0031 final report, is also used to record and analyze data from the engine dynamometer test facility. Up to 48 pressures can be measured via a Multiple Scanivalve System which sends transducer signals to the data acquisition system. Engine torque and speed signals are taken directly from the dynamometer controller into the Hewlett Packard 3052A. A Hewlett Packard 5300B counter sends turbocharger rotational speed directly to the 3052A data acquisition system.

Engine instrumentation included four compressor inlet and four compressor exit temperatures and static pressures. The turbine also had four temperatures and static pressures at the inlet and exit. Iron constantine thermocouples were used at all locations. Compressor inlet and turbine inlet stagnation pressures were calculated from measured static pressure, temperature, mass flow, and the known area. Engine air flow is measured using a Meriam model 50MC2-4F Laminar Flow Element placed some 35 feet upstream of the compressor inlet. This 35 foot length also contains a 55 gallon drum used to dampen the pulses emitted from the engine. Fuel flow was measured using a balance and weights. The time required to consume a known mass of fuel was measured thereby giving fuel mass flow rate. The relative humidity, fuel weight, and time are entered into the data acquisition computer manually. Fuel temperature (entering the fuel pump) and crankcase oil temperature were measured for documenation purposes.

### TEST PROCEDURE

The John Deere 4239T diesel engine with the Aerodyne Dallas VATN turbocharger was mounted on the engine dynamometer and instrumented. The data acquisition and analysis computer program which was previously generated was used for this test. This program was used to acquire and analyze engine dynamometer data taken for the same engine operating with the bill of materials turbocharger, an Airesearch T04. This baseline test was run previous to the current contract and will be compared to the VATN turbocharger results in the next report section.

The test was conducted by operating the engine at speeds of 1000, 1500, 2000, and 2500 rpm, and loads of 0, 25, 50, 75, and 100% at each speed. At each point in this matrix two or three data points were taken at different turbine vane throat dimensions. At 1000, 1500, 2000, and 2500 rpm, 100% torque values were 197.5, 216.5, 209.0, and 194.3 ft-lb respectively. In addition, data was also taken at the maximum fueling which the fuel pump would deliver at 1000, 1500, 2000, and 2500 rpm. An attempt was made to take data at idle speed and various loads but engine over heating was experienced and this portion of the test plan was deleted. One data point was taken at 747 rpm and 178 ft-lb (100% load).

TEST RESULTS

Copies of the computer output sheets are shown in the Appendix. Reading numbers (Rdg #) 1, 2, 3, 19, and 46 were for checkout purposes; fuel consumption measurements were not taken at these points. Therefore, of the 67 readings taken, 63 are valid fuel consumption points. The BSFC (brake specific fuel consumption) results are shown in figures 9, 10, 11, and 12 for 1000, 1500, 2000, and 2500 rpm respectively. Also shown in these figures are the BSFC values for the bill of materials, fixed area, turbocharger (T04) at the same operating conditions. This data was taken on the same engine, same dynamometer, and using the same measurement techinques and data analysis program. The effect of the VATN turbocharger, as compared to the fixed area turbocharger, on engine fuel consumption can be stated succinctly as follows. At every point in the speed/load operating envelope of the engine there is a VATN turbocharger vane position at which the engine fuel consumption is improved as compared to that with the fixed area turbocharger. The improvement was 2 to 9% for all data points except one which was 31%.

The data shown in the Appendix includes two compressor efficiency values. The first value is calculated based on measured compressor pressure ratio, inlet temperature and exit temperature. The second efficiency corrected the compressor exit temperature by the 0.0008 Btu/$^{o}$F/sec constant discussed earlier. Recall that this constant approximately accounts for heat transfer between turbine and compressor. This data was plotted as a function of compressor pressure ratio for each of the four engine speeds. Also included in these figures, 13 through 16, is the compressor efficiency from the compressor map. It can be seen from figures 13 through 16 that the 0.0008 overall heat transfer constant corrects the compressor efficiencies measured on the engine back to the compressor map values. The data at 1000 rpm, figure 13, shows the most divergence between corrected and map efficiencies. This is most likely due to the effect of low Reynolds numbers at low flow rates.

FIGURE 9-

SPECIFIC FUEL CONSUMPTION
AS A FUNCTION OF VANE THROAT POSITION
AT 1000 RPM FOR A JOHN DEERE
3.9 LITER, D.I. DIESEL

| | BMEP | |
|---|---|---|
| LOAD | PSI | BAR |
| ○ 25% | 31.2 | 2.15 |
| □ 50% | 62.4 | 4.30 |
| ◇ 75% | 93.5 | 6.44 |
| △ 100% | 124.6 | 8.60 |

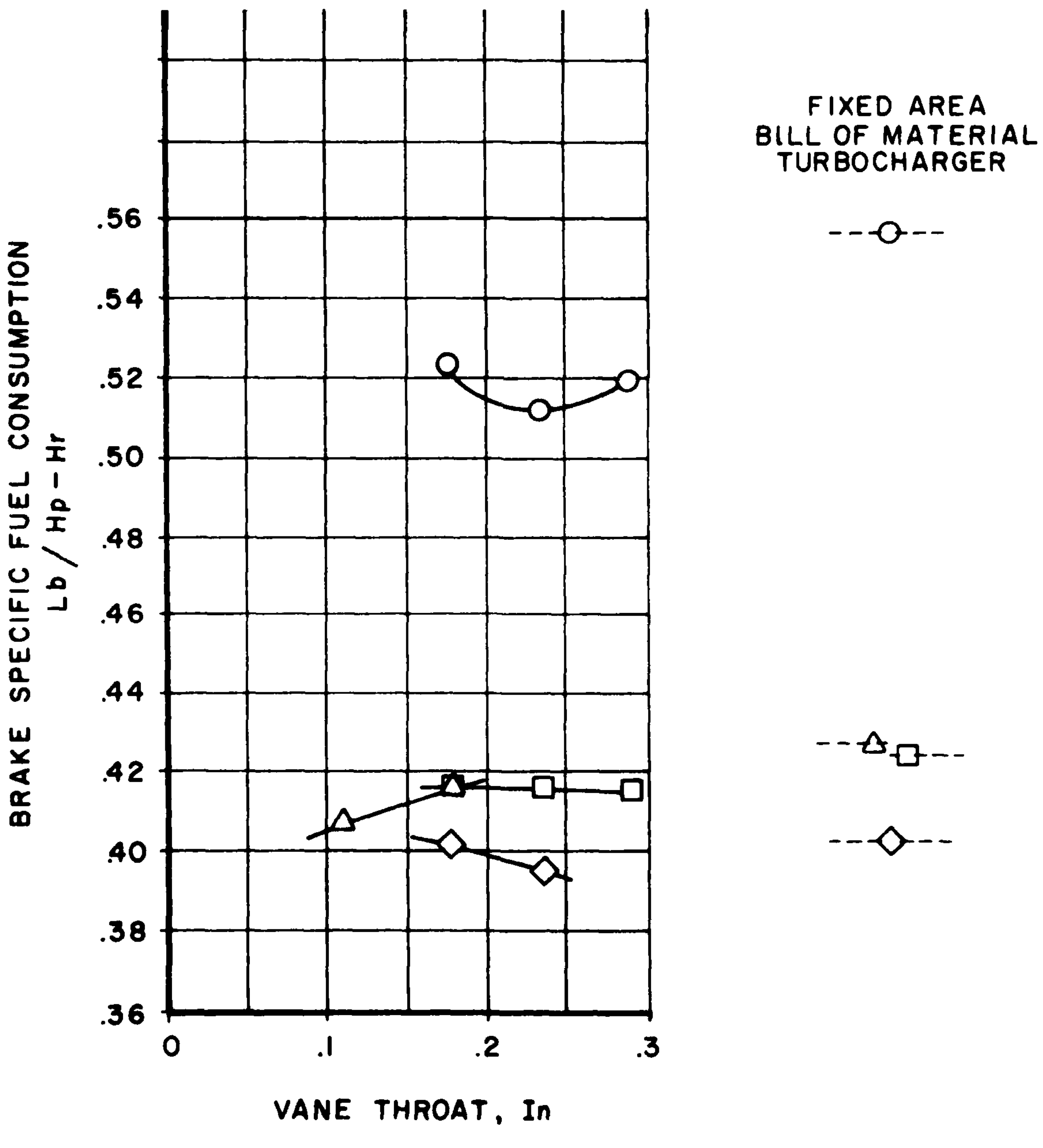


FIGURE 10-
SPECIFIC FUEL CONSUMPTION
AS A FUNCTION OF VANE THROAT POSITION
AT 1500 RPM FOR A JOHN DEERE
3.9 LITER, D.I. DIESEL

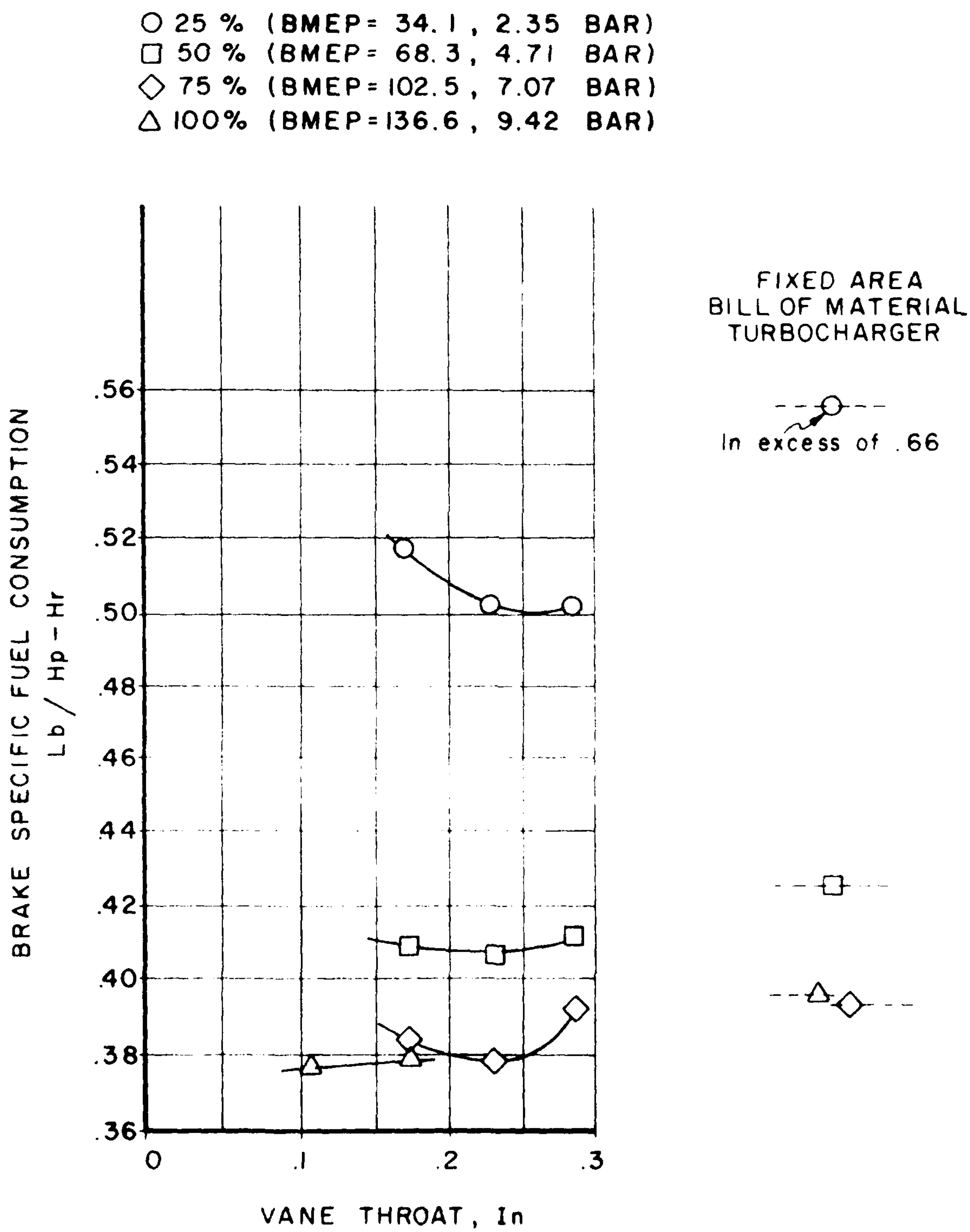


FIGURE II-

SPECIFIC FUEL CONSUMPTION

AS A FUNCTION OF VANE THROAT POSITION

AT 2000 RPM FOR A JOHN DEERE

3.9 LITER, D.I. DIESEL

| LOAD | BMEP PSI | BMEP BAR |
|---|---|---|
| ○ 25% | 33.0 | 2.27 |
| □ 50% | 65.9 | 4.55 |
| ◇ 75% | 98.9 | 6.82 |
| △ 100% | 131.9 | 9.09 |

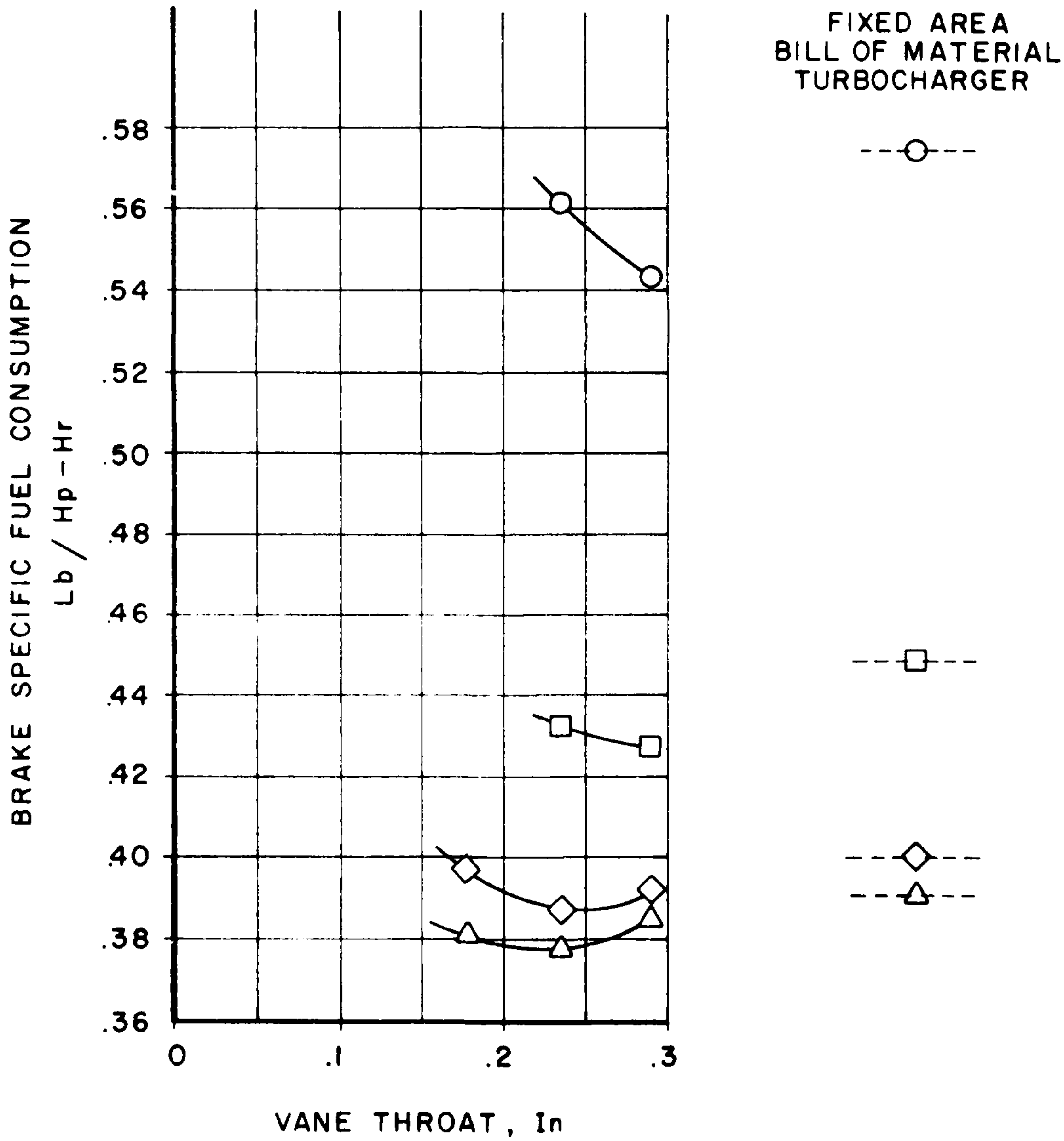


FIGURE 12-

SPECIFIC FUEL CONSUMPTION

AS A FUNCTION OF VANE THROAT POSITION

AT 2500 RPM FOR A JOHN DEERE

3.9 LITER, D.I. DIESEL

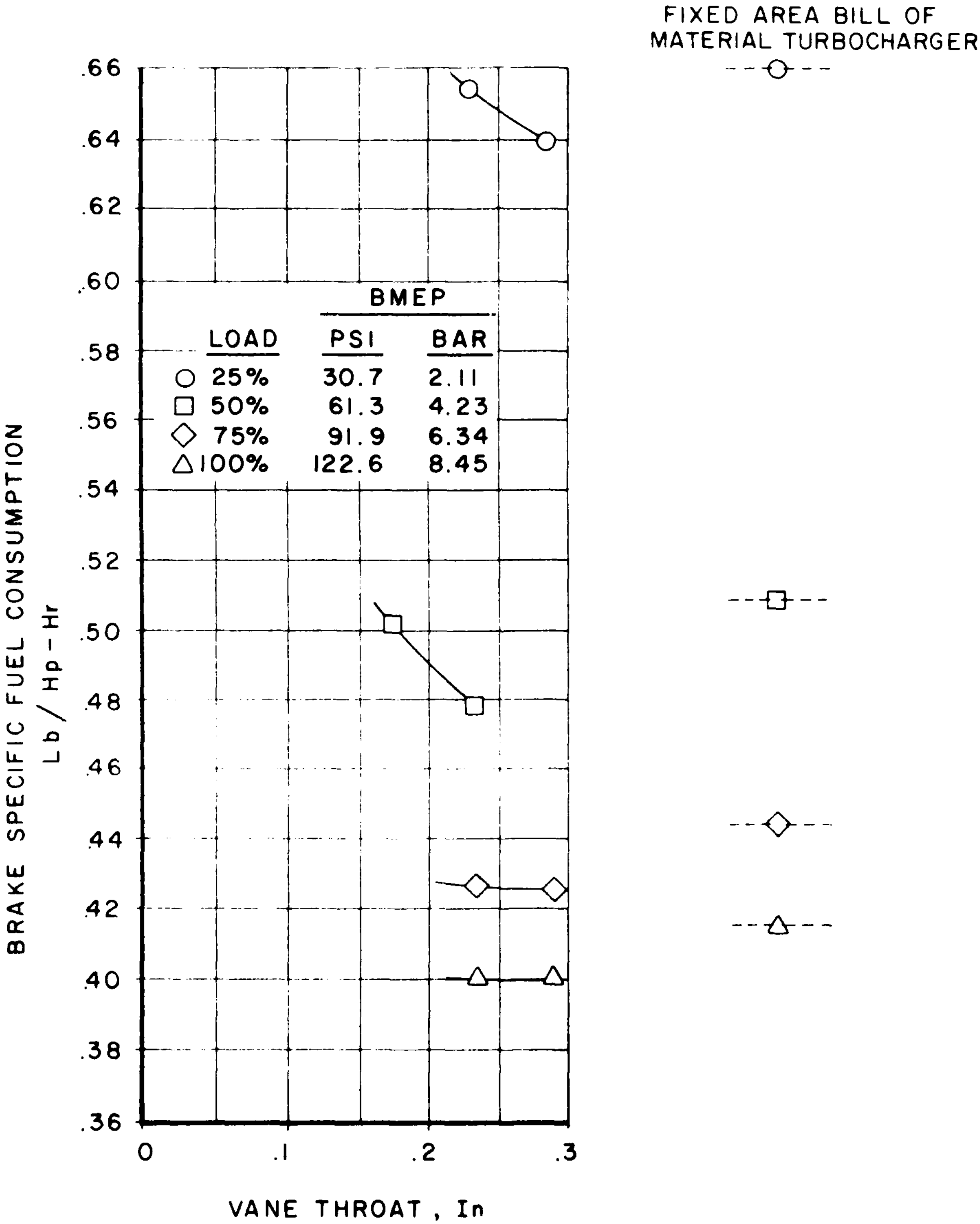


FIGURE 13-

APPARENT EFFECT OF HEAT TRANSFER ON COMPRESSOR EFFICIENCY

DATA FROM JOHN DEERE 3.9 LITER DIESEL

1000 RPM ENGINE SPEED
OPERATING LINE

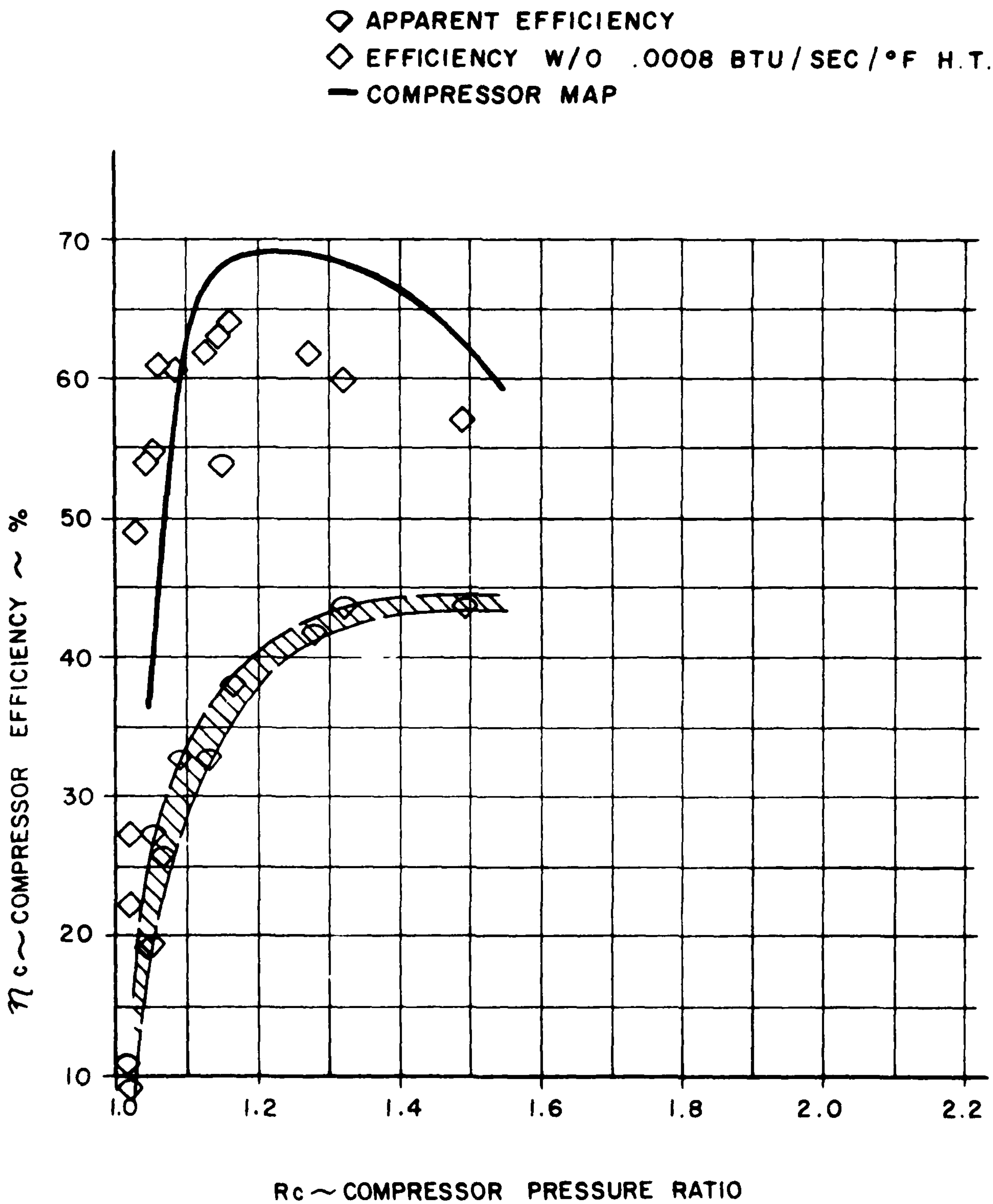


FIGURE 14-

APPARENT EFFECT OF HEAT TRANSFER
ON COMPRESSOR EFFICIENCY
DATA FROM JOHN DEERE 3.9 LITER DIESEL

1500 RPM ENGINE SPEED
OPERATING LINE

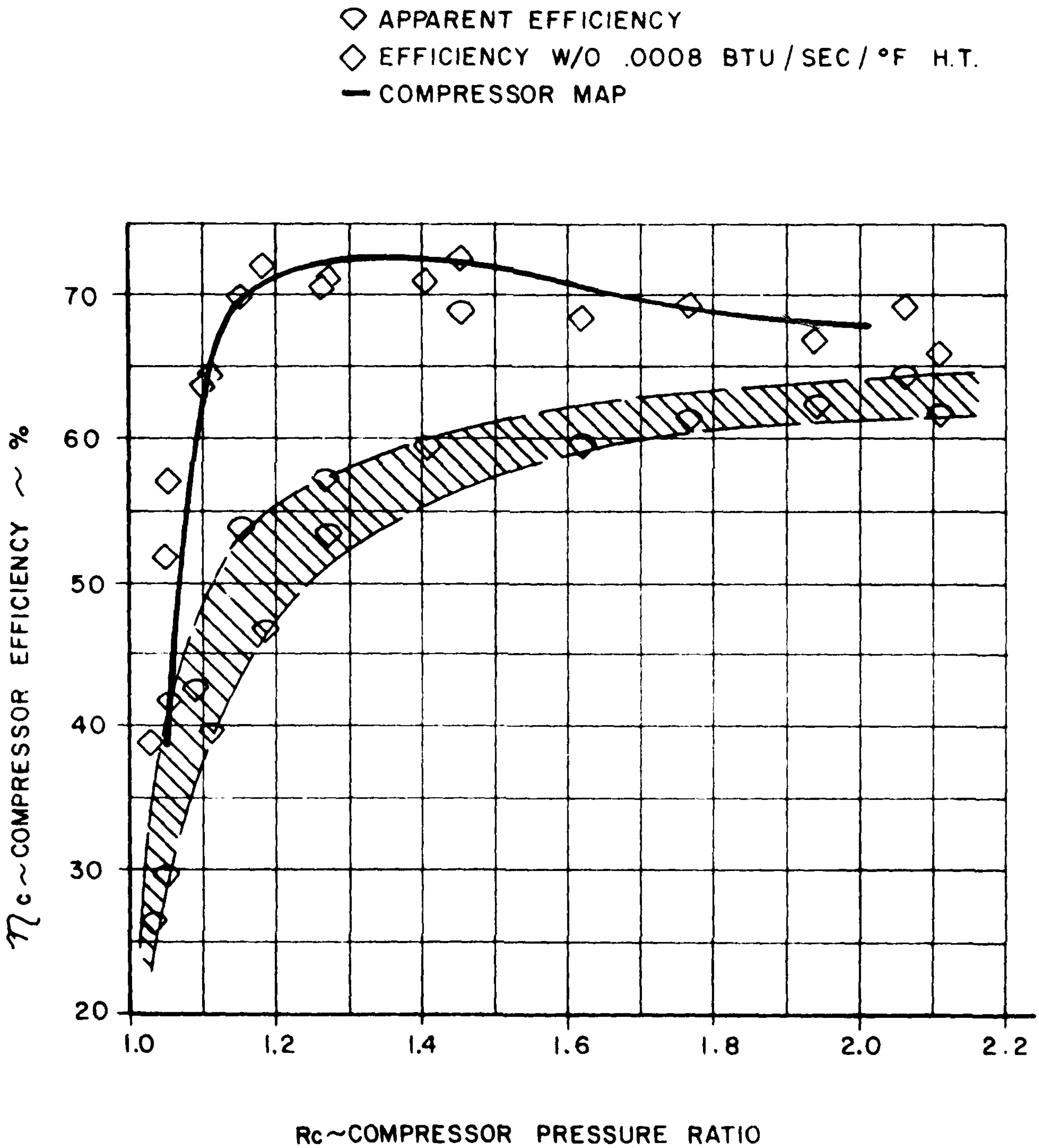


FIGURE 15-
APPARENT EFFECT OF HEAT TRANSFER
ON COMPRESSOR EFFICIENCY
DATA FROM JOHN DEERE 3.9 LITER DIESEL

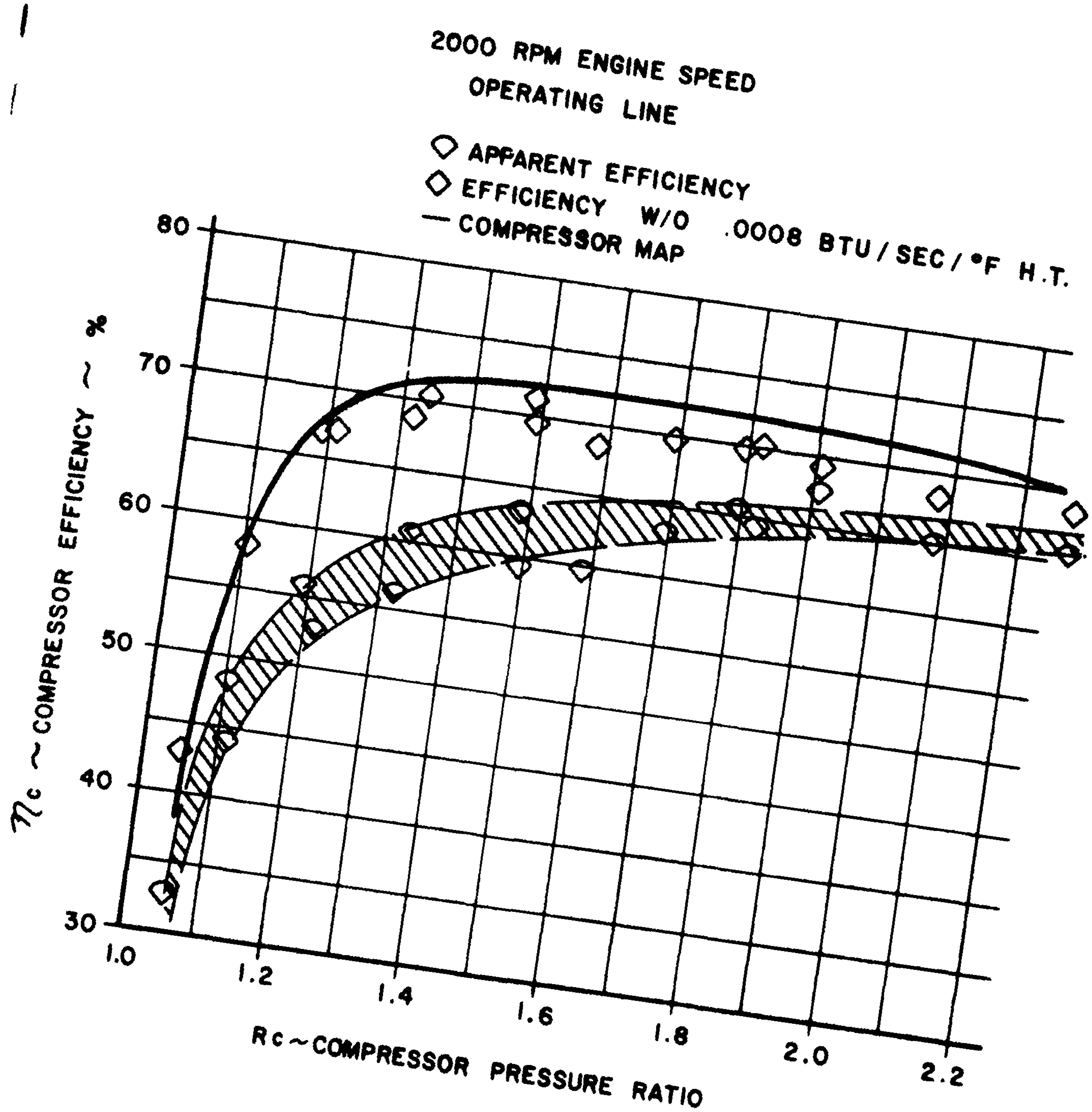


FIGURE 16-

APPARENT EFFECT OF HEAT TRANSFER
ON COMPRESSOR EFFICIENCY
DATA FROM JOHN DEERE 3.9 LITER DIESEL

2500 RPM ENGINE SPEED
OPERATING LINE

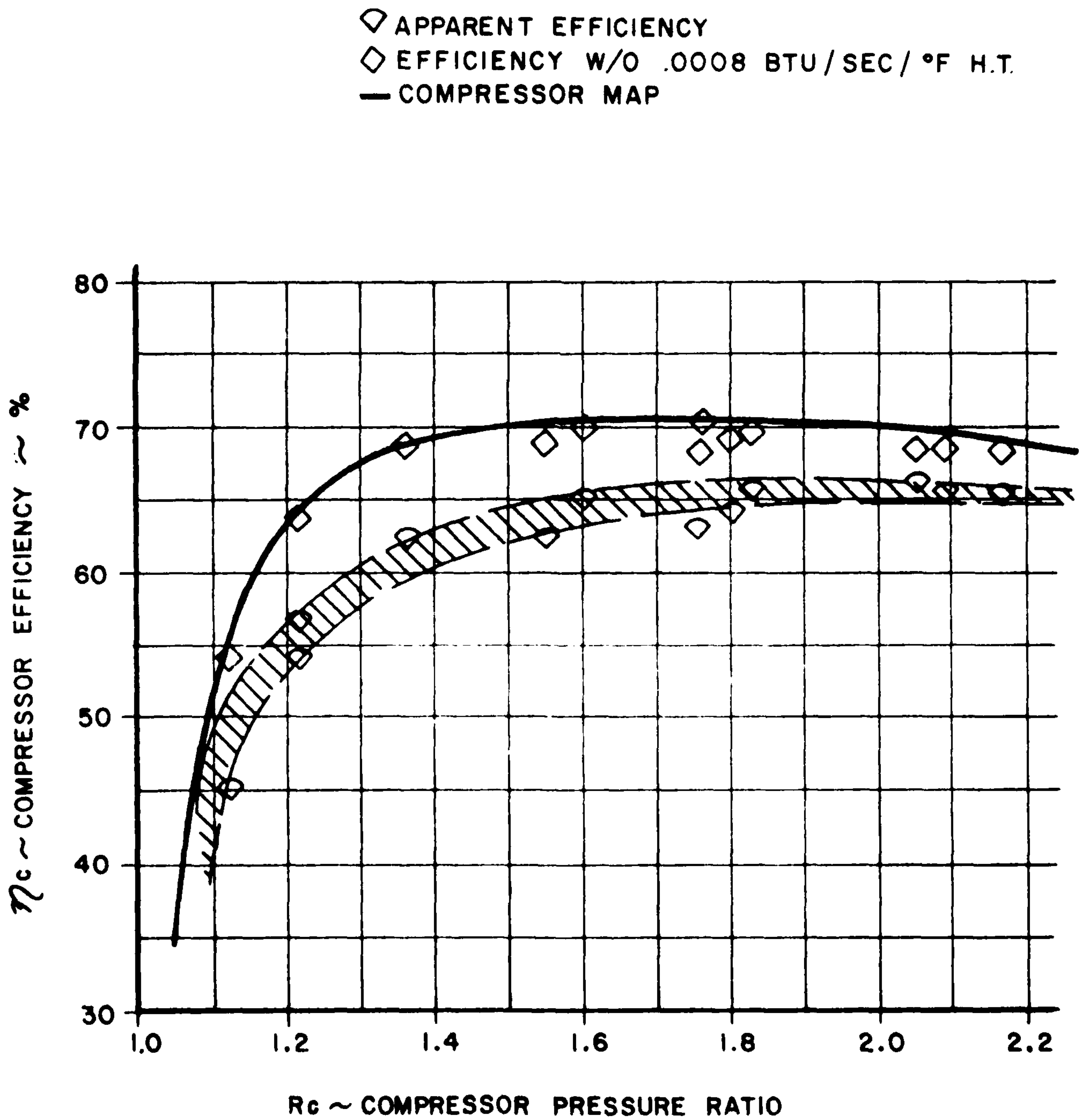
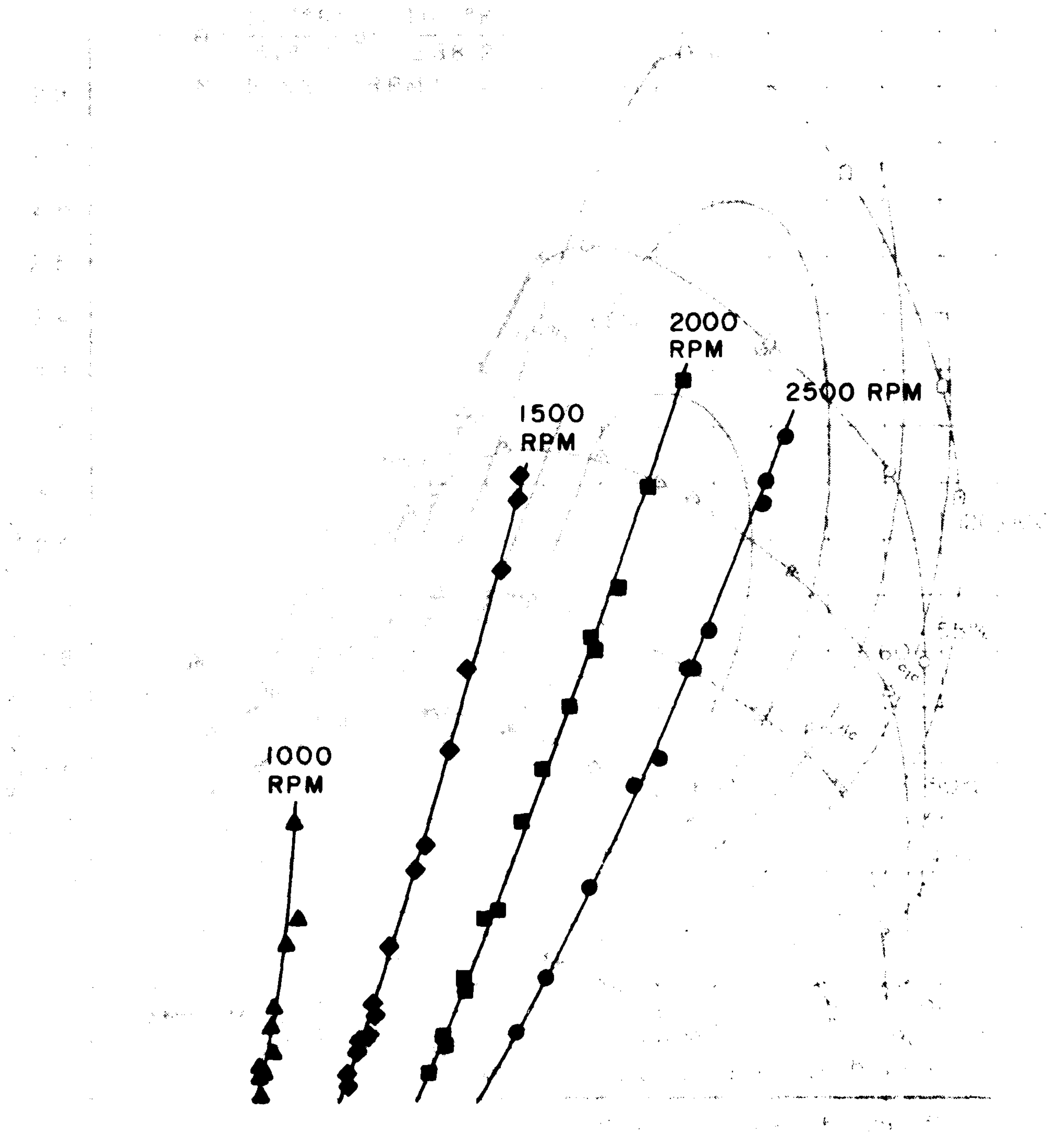


FIGURE 17-
COMPRESSOR MAP WITH 4239T ENGINE SPEED LINES



# IV. ROTOR BEARING SYSTEM ANALYSIS AND TEST

The purpose of this portion of the contract was to make a limited demonstration of durability and gain more experience with respect to the ball bearing system which supports the rotor. This phase was to conclude by running a turbocharger for 700 hours. As illustrated in figure 1, both wheels are overhung from the bearings, both of which are full complement (10 balls each) angular contact bearings with a preload spring between them.

## ANALYSIS

The original program was to have an analysis made of bearing life by an "outside" consultant or bearing maunfacture. This analysis was to consider the influence of speed, radial clearance, inner and outer race curvature, preload, and material hardness. The results of this analysis was to be used as a guide in defining a test program. No source could be found to make the analysis in a timely fashion within the cost constraints of the contract. Therefore, the analysis phase was cancelled.

## TEST PLAN

The test plan was defined based on past experience with small instrument bearings in lieu of the "outside" analysis. The objective was to define a series of configurations which would allow speed, radial clearance, preload, number of balls, balance, and type of lubricant to be investigated. Table I lists the test configuration idenification and the associated value of the various parameters.

## TEST FACILITY

In order to test these various configurations, a bearing shaft test rig facility was fabricated. This facility was a 354 CID, 6 cylinder, diesel engine the exhaust of which was used to drive an Aerodyne turbocharger. The compressor discharge was fed into a plenum which inturn supplied the compressed air to each of 24 bearing shaft test rigs. Each test rig was composed of a bearing and shaft arrangement the same as the turbocharger. On the end of the shaft, where the turbine rotor would be, an air turbine was machined. Figure 18 is a photograph showing the various parts which make up a test rig. A valve was placed between each test rig and the plenum in order to control the flow, and therefore speed, of each rig. The turbocharger, which supplied the pressurized air, was controlled by moving the turbine vanes and bleeding air to ambient at locations where no rigs were installed.

## TEST RESULTS

The test rig configurations listed in Table I were built, installed, and run. Bearing failures began to occur after only 10 hours of running. At first it was felt that the failed configurations incorporated parameter combinations which caused the failures. After 30-50 hours all but a few rigs had failed. At this point a detailed investigation of the grinding process revealed that the inner bearing races, which are ground on the shaft, were not accurate. This was actually traced to the dressing of the grinding wheel. The diamond did not travel in a plane intersecting the axis of rotation of the grinding wheel. This resulted in a non-circular dress of the wheel. The local curvature at the point of contact with the balls was almost the same as the ball curvature. This gave a very large contact area which caused frictional wear. The problem was corrected. Also a different grit grinding wheel was procured which gave an improved surface finish. At this point in time, there were only four test rig shafts remaining and it was not feasible to make an additional 24 new shafts in the remaining contract time. These four shafts were ground to a larger radius of curvature than the original rigs; 0.070 as opposed to .067 inch. This increase in radius of curvature reduced the sensitivity of the race being an arc of a "perfect" circle.

The four rigs were built to the following configuration and run for the time indicated. (See Table 1 for configuration definition).

| Config. | Hours run |
|---|---|
| N2A | 312 |
| N8A | 456 |
| N1A | 408 |
| N/2A | 672 |

At this point 1011 hours had been accumulated on the Aerodyne turbocharger which was suppling the compressed air to the plenum. It was felt that, although the original testing was not complete, the turbocharger had run for well over the 700 hour goal, namely for 1011 hours, without incident. During this time the turbocharger operated at speeds between 70000 and 78000 rpm. The turbocharger was disassembled and inspected. The VATN system was still functional and the bearings were in excellent condition. The turbocharger was subsequently installed on a diesel powered automobile and continued to perform.

TABLE I - Bearing test configuration

AerodyneDallas

| Test ID | Speed rpm X $10^3$ | Radial Cl X $10^{-3}$ in | Inner Trk Curv % | Outer Trk Curv % | Preload LB | Out Of Bal | Hardness Rc | # of Balls | Lube |
|---|---|---|---|---|---|---|---|---|---|
| N1A | 120 | 5 | 52 | 52 | 9 | 0 | 61 | 10 | "B" |
| N2A | | 8 | | | | | | | |
| N3A | | 11 | | | | | | | |
| N4A | 90 | 5 | | | | | | | |
| N5A | | 8 | | | | | | | |
| N6A | | 11 | | | | | | | |
| N7A | 120 | 5 | | | 5 | | | | |
| N8A | | 8 | | | | | | | |
| N9A | | 11 | | | | | | | |
| N10A | | 5 | | | 9 | | | 9 | |
| N11A | | 8 | | | | | | | |
| N12A | | 11 | | | | | | | |
| N13A | | 8 | | | 5 | limit | | 9 | |
| N14A | | | | | 5 | | | 10 | |
| N15A | | | | | 9 | | | 9 | |
| N16A | | | | | 9 | | | 10 | |
| N17A | | | | | 9 | 0 | | 10 | HUMB |
| N18A | | | | | | | | | ISOFLX |
| N2B | | | | | | | | | B |
| N2C | | | | | | | | | |
| O2A | | | | | | | | | |
| O17A | | | | | | | | | HUMB |
| O18A | | | | | | | | | ISOFLX |

FIGURE 18a - BEARING SHAFT TEST FACILITY

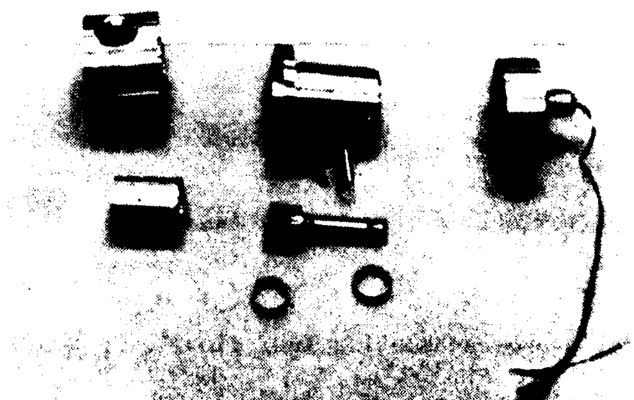


FIGURE 18b-TEST RIG (ONE OF 24)

## V. MATH MODEL

A math model more elaborate than that included in the previous contract was generated. Correlations used in the current math model were deduced from data taken on the John Deere 4239T diesel engine.

### MODEL GENERATION

First order principles augmented by correlations are used to model the engine. The turbocharger modelling is composed of a compressor map non-dimensionalized in terms of parameters which allow the map to be scaled to different compressor trims. Turbine performance is characterized by a series of maps at each of five turbine vane positions. Heat transfer from turbine to compressor and leakage from turbine to compressor and turbine to ambient can be accounted for in the calculation.

The frictional loss of the engine is expressed in terms of mean effective pressure by the following equation:

$$Fmep = (SK*NE/6)*(1.555 \times 10^{-5}*Imep + 0.011818) + 0.01183*Imep + 8.797$$

where:

Fmep = friction mean effective pressure — psi

SK = stroke — inches

NE = engine speed — rpm

Imep = indicated mean effective pressure — psi

The difference in pressure between intake and exhaust manifolds (Pim - Pem) is not included in this definition of Fmep. Brake mean effective pressure, BMEP (psi), is expressed as:

$$BMEP = Imep - Fmep + (Pim - Pem)$$

Imep is expressed as:

$$Imep = 1.1295 \times 10^{6}*CE*EFFith/(DS*NE)$$

where:

CE = chemical energy available, fuel flow*lower heating value - Btu/sec

EFFith = indicated thermal efficiency

DS = engine displacement - cubic inches

Pim = intake manifold pressure - psia

Pem = exhaust manifold pressure - psia

Indicated thermal efficiency is determined from a correlation which expresses EFFith as a function of air/fuel ratio and engine speed, (see figure 19). This correlation was derived from 4239T engine test data taken at Aerodyne with the T04 turbocharger.

The exhaust manifold temperature is determined by calculating an ideal combustion temperature and an ideal temperature after expansion to either the full piston stroke change in volume or exhaust manifold pressure, which ever is greater. Two energy losses are assumed to occur which reduces the exhaust manifold temperature below the calculated ideal value. An adjustment is first made to the ideal combustion temperature to account for combustion inefficiency. This is done by arbitarly assuming a 98% combustion efficiency at the air/fuel ratio where maximum indicated thermal efficiency occurs for a given engine speed, (see figure 19). Then the combustion efficiency is further reduced by assuming that it is proportional to the change in indicated thermal efficiency which occurred due to the air/fuel ratio not being equal to the "max EFFith" value. The other heat loss term is calculated from heat transfer to the coolant. With these two adjustments, a gas temperature "at the exhaust port" can be calculated. Heat loss via convection and radiation from the exhaust manifold is estimated from basic heat transfer concepts. This adjustment is made to calculate turbine inlet temperature. If heat transfer is assumed to take place between turbo-charger turbine and compressor, the loss is taken prior to the turbine expansion process.

Air mass flow rate through the engine is calculated using a volumetric efficiency which is corrected for the pressure difference across the engine (Pim - Pem). This parameter has been named base volumetric efficiency. For a four cycle engine, volumetric efficiency is defined as:

$$EFFVOL = 3456 * \dot{m}chg / (Pchg * DS * NE)$$

where:

EFFVOL = volumetric efficiency

$\dot{m}chg$ = charge mass flow rate - lbm/min

Pchg = charge density at intake value - $lbm/ft^3$

DS = displacement - cubic inches

NE = engine speed - rpm

By assuming that there is very little valve overlap and by knowing intake and exhaust manifold pressure the following "first order" correction is made to volumetric efficiency to get base volumetric efficiency:

$$EFFVOL\ base = EFFVOL/(1-(Pem/Pim-1)/(CR-1))$$

where:

EFFVOL base = base volumetric efficiency

Pem = exhaust manifold pressure - psia

Pim = intake manifold pressure - psia

CR = compression ratio

This relation also does not take into account any tuning effects of the intake or exhaust manifold. Base volumetric efficiency was calculated for the John Deere 4239T engine tested with the T04 turbocharger at Aerodyne. These data were correlated against the square root of intake manifold temperature is proportional to acoustic velocity at the intake valve, (see figure 20).

Smoke and emissions data taken during the previous contract at Southwest Research Institute were correlated. Carbon monoxide (CO) and unburned hydrocarbons (HC) were expressed as volumetric ratio to fuel i.e. parts of CO or HC per million parts of fuel (in a gaseous state). The independent variable for both correlations was chosen as the average temperature of combustion where combustion was assumed to be the ideal constant pressure process. Figures 21 and 22 show linear least square fits of the log of the dependent parameter with the independent parameter. Oxides of nitrogen ($NO_x$) were also correlated against the average combustion temperature. In this case, the amount of polutant was expressed as the volumetric ratio to unburned air (parts of $NO_2$ per million parts of unburned air). A linear least squares function was fitted to the log of the $NO_x$ parameter versus the average combustion temperature, (see figure 23). The Bosch smoke number was obtained from the percent opacity data taken by Southwest Research Institute using the SAE handbook correlated for a 4 inch stack outlet diameter. The independent correlation parameter was chosen to be the ratio of unburned fuel/air. Unburned fuel was estimated in the same manner as combustion inefficiency was accounted for in determining exhaust manifold temperature discribed previously. Figure 24 shows this correlation.

The entire model involved a multitude of iteration and subiteration loops. The model was programmed in BASIC on a TRS80 computer. Conditions from the previous engine testing with T04 turbocharger were calculated using the math model. Calculations were also made for some of the data points taken from current contract with the Aerodyne turbocharger. Table II lists the comparison between calculated and measured brake specific fuel consumption values for the 4239T engine operating with the T04, fixed area, turbocharger. Table III lists similar data for the Aerodyne turbocharger.

FIGURE 19-

INDICATED THERMAL EFFICIENCY CORRELATION

(FROM ENGINE TEST AT AERODYNE WITH T04 ON 4239T)

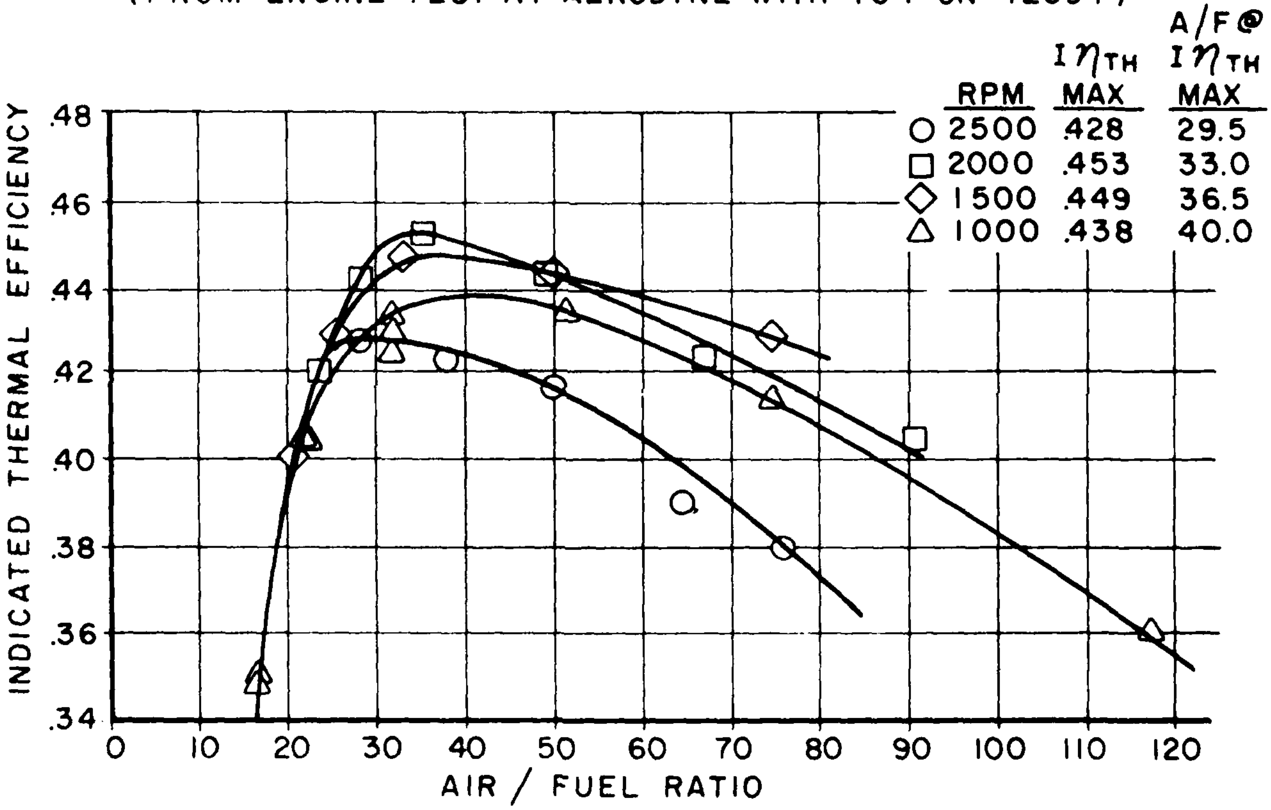


FIGURE 20-
BASE VOLUMETRIC EFFICIENCY CORRELATION
(FROM ENGINE TEST AT AERODYNE WITH T04 ON 4239T)

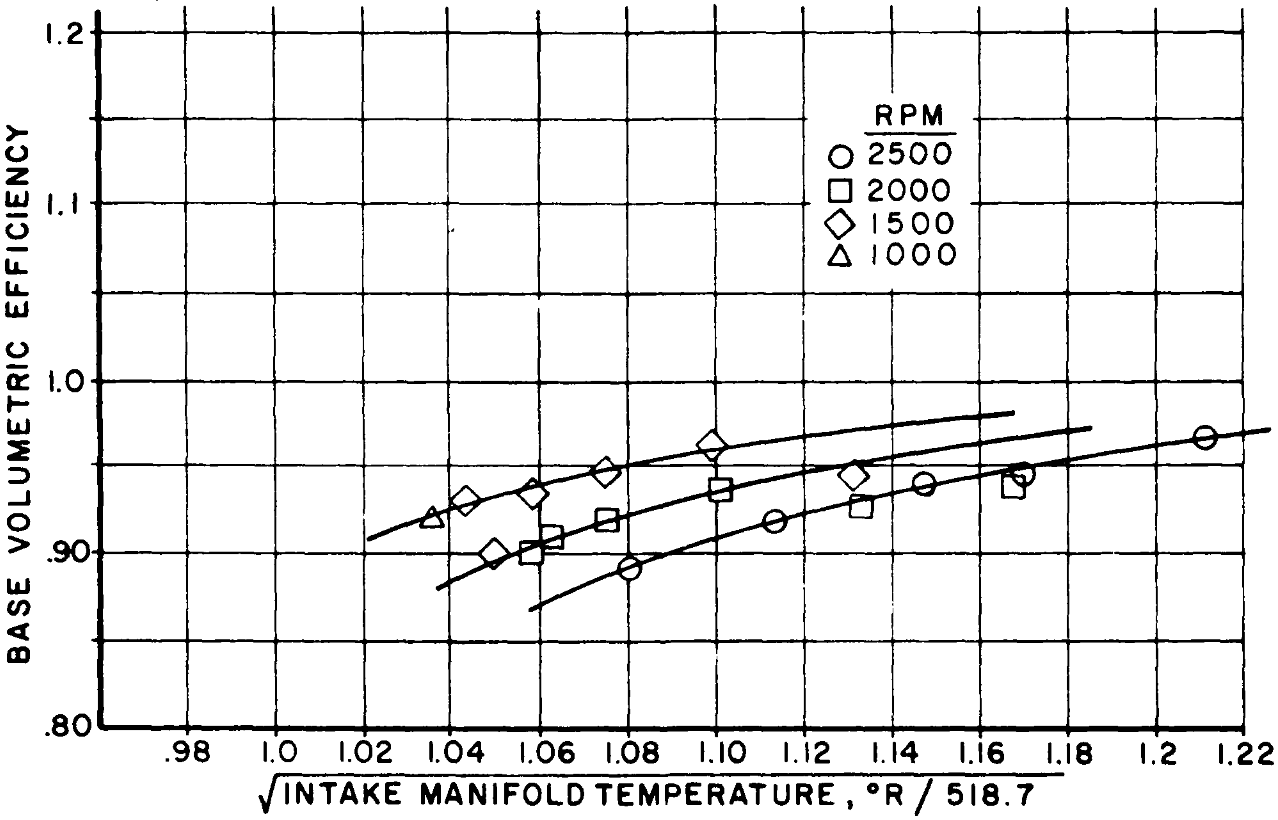


FIGURE 21- CO CORRELATION

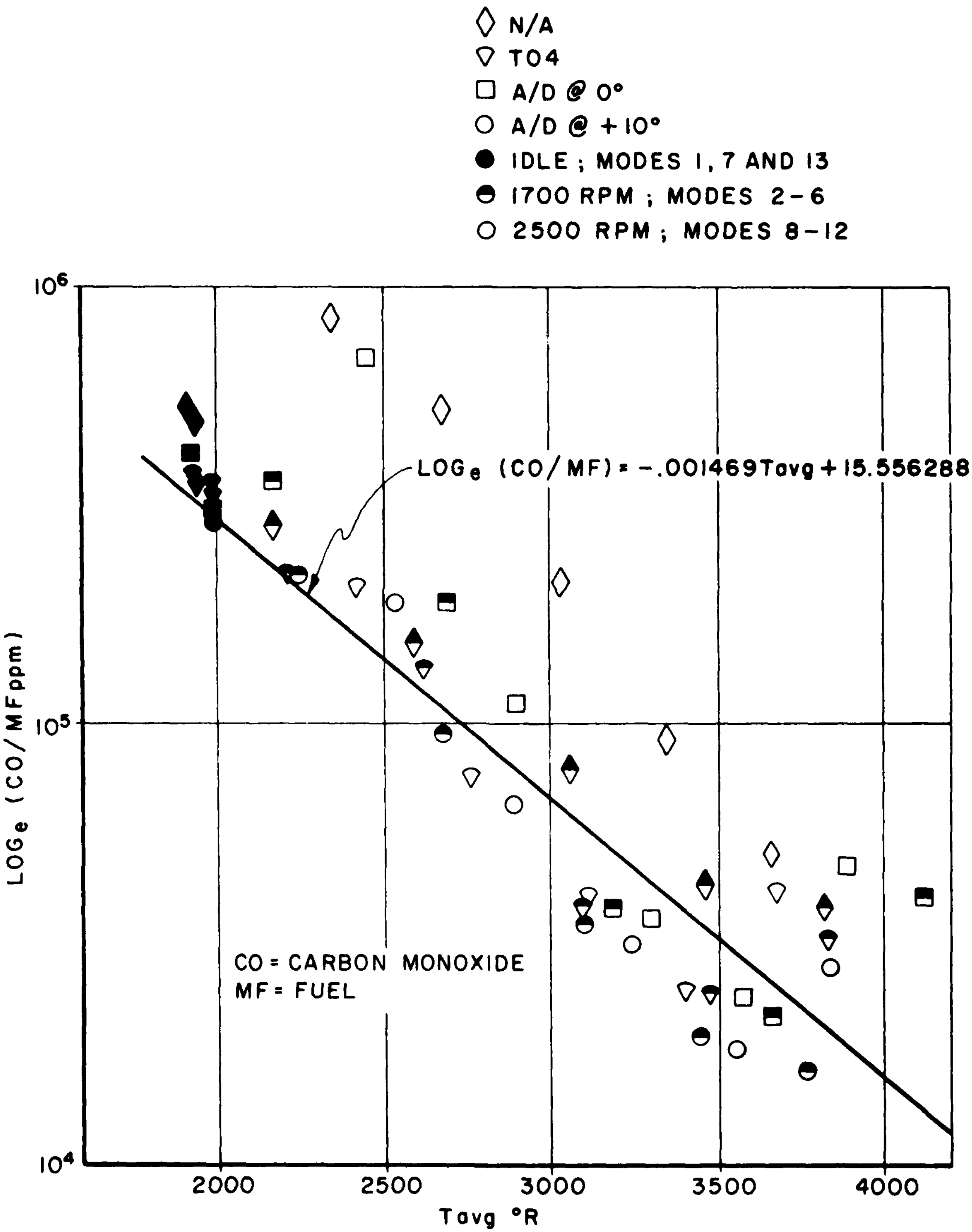
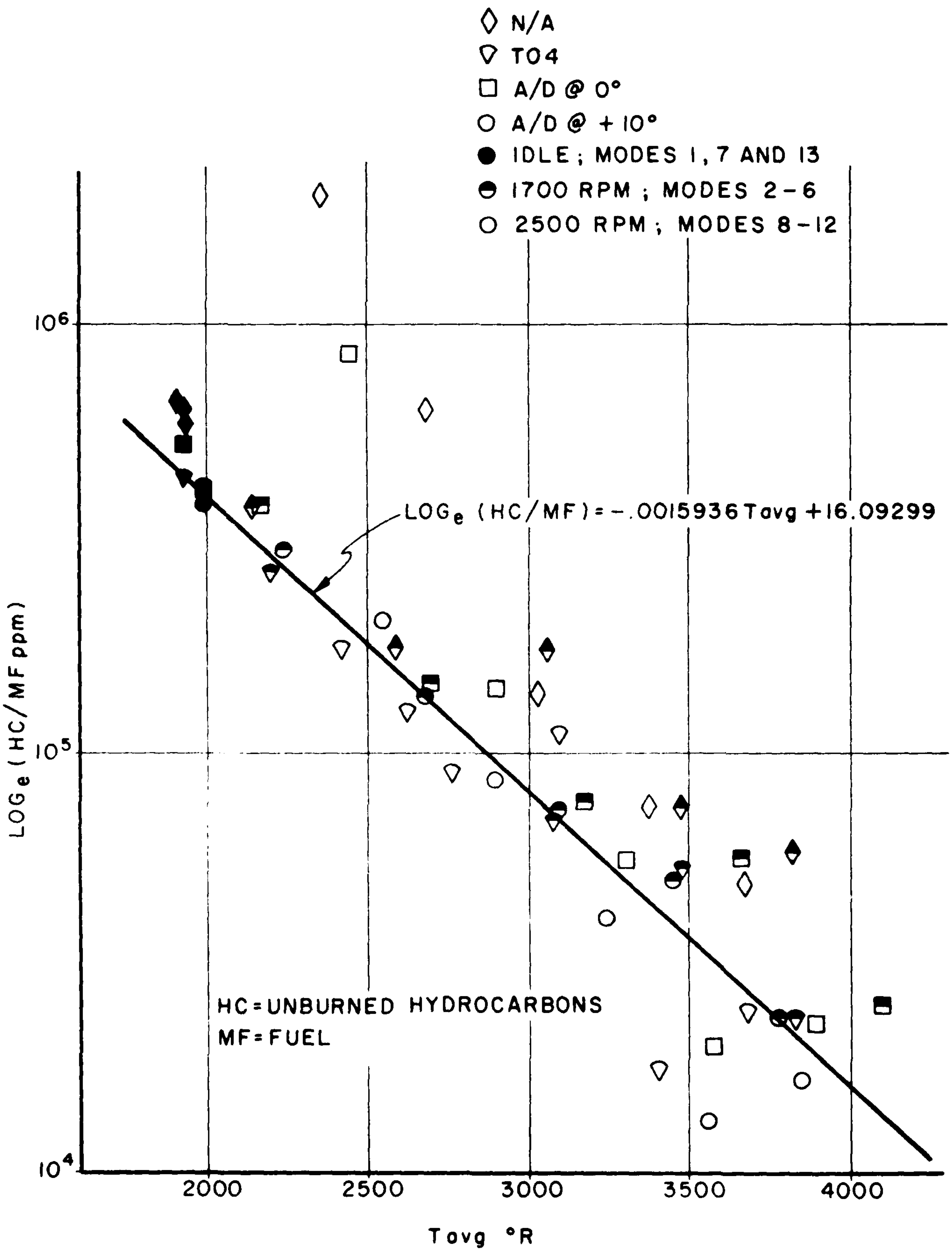


FIGURE 22- HC CORRELATION



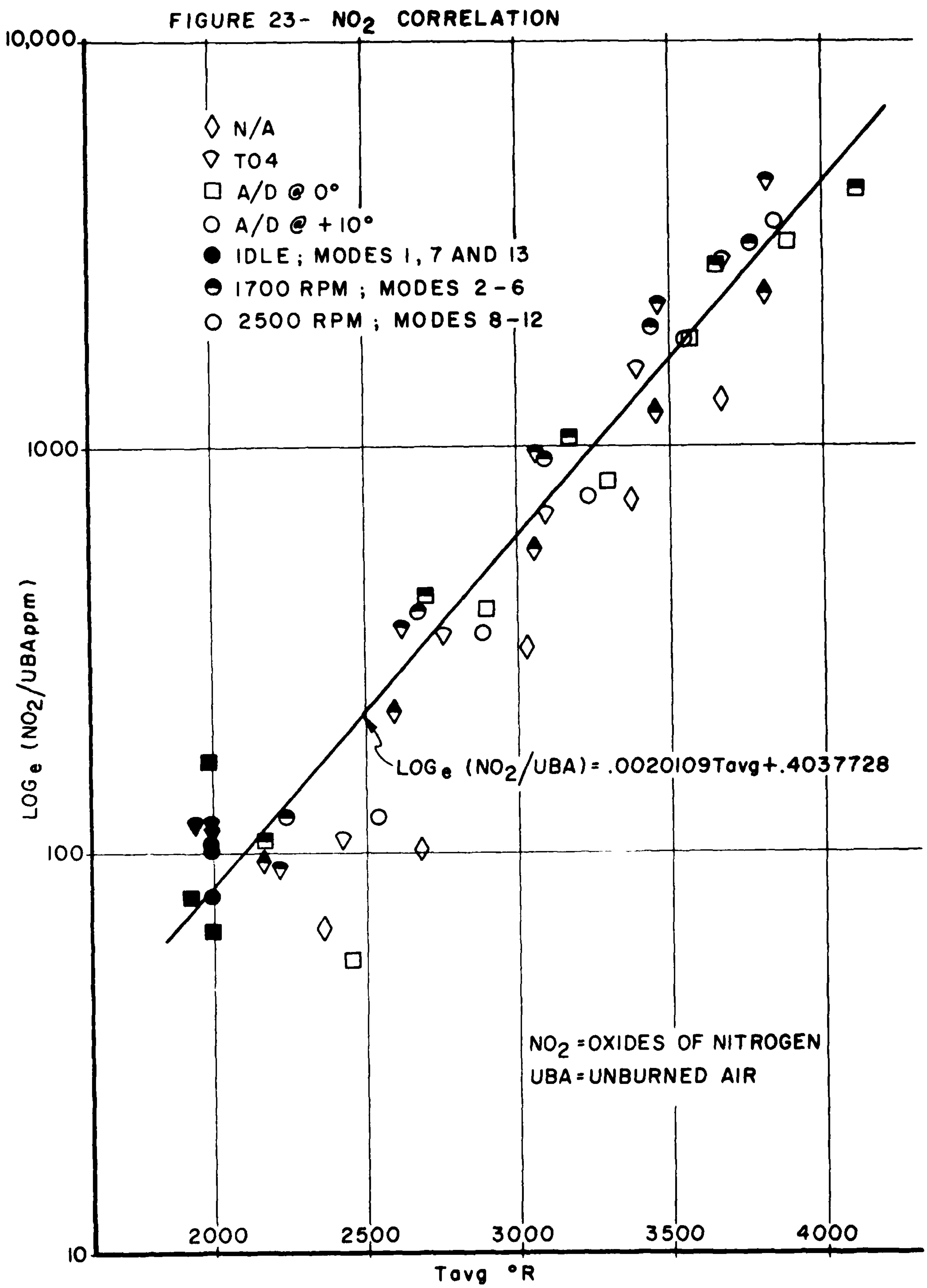


FIGURE 23- NO2 CORRELATION
N/A
T04
A/D @ 0°
A/D @ +10°
IDLE; MODES 1, 7 AND 13
1700 RPM; MODES 2-6
2500 RPM; MODES 8-12
LOGe (NO2/UBA)= .0020109Tavg+.4037728
NO2 =OXIDES OF NITROGEN
UBA=UNBURNED AIR
LOGe (NO2/UBAppm)
10,000
1000
100
10
2000
2500
3000
3500
4000
Tavg °R

FIGURE 24- BOSCH SMOKE NUMBER CORRELATION BASED ON SOUTHWEST RESEARCH INST. DATA

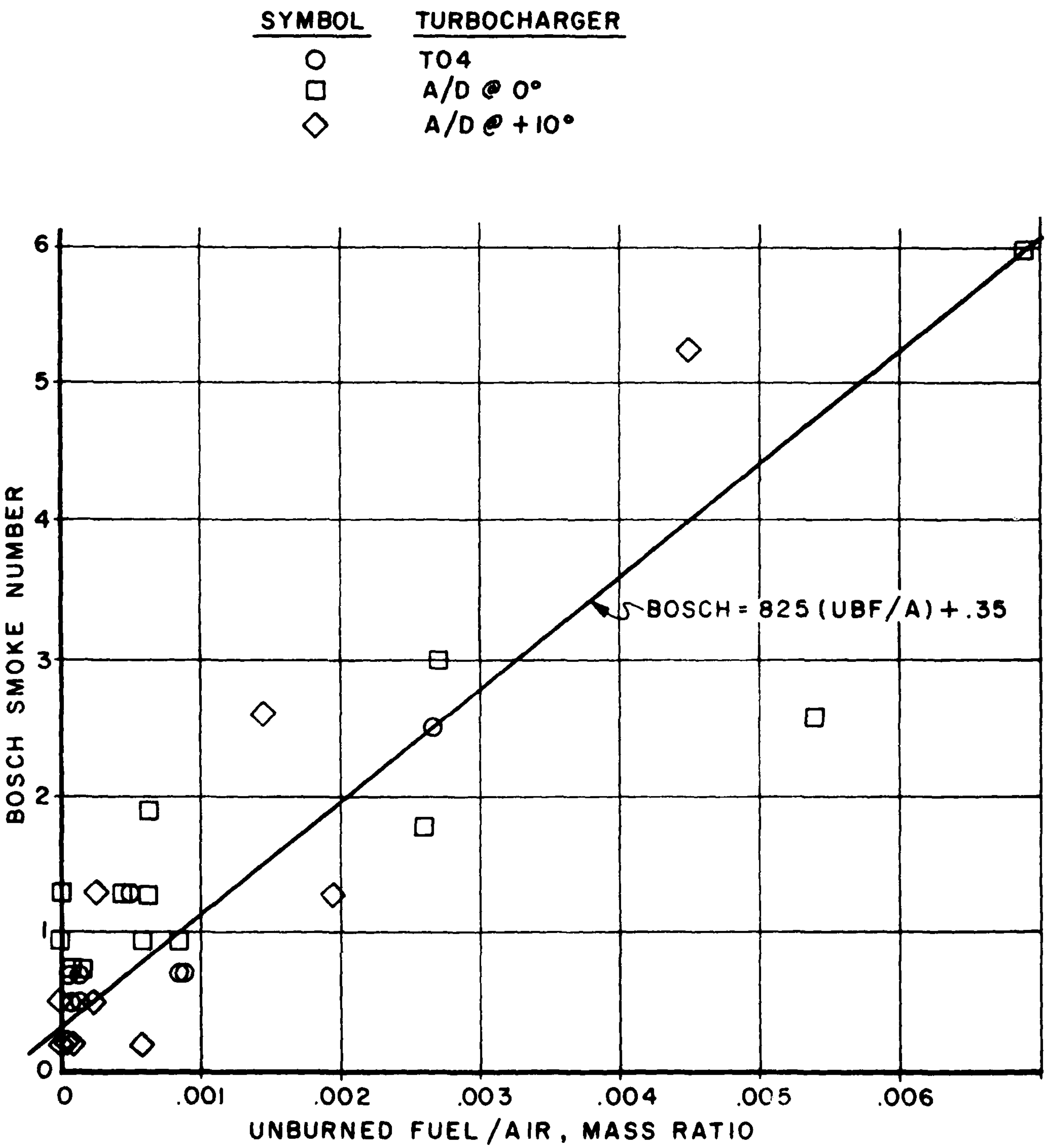


TABLE II - Calculated and measured BSFC values for fixed area turbocharger

| Engine Speed (rpm) | Load (ft lb) | BSFC (lb/hp-hr) meas | calc | error |
|---|---|---|---|---|
| 2500 | 197 | .414 | .4153 | +0.3% |
| 2500 | 99 | .504 | .5034 | -0.1% |
| 1500 | 232 | .401 | .4250 | +6.0% |
| 1500 | 173 | .393 | .4059 | +3.3% |
| 1500 | 122 | .409 | .4104 | +0.3% |
| 1500 | 61 | .509 | .5079 | -0.2% |
| | | | avg. = +1.6% | |

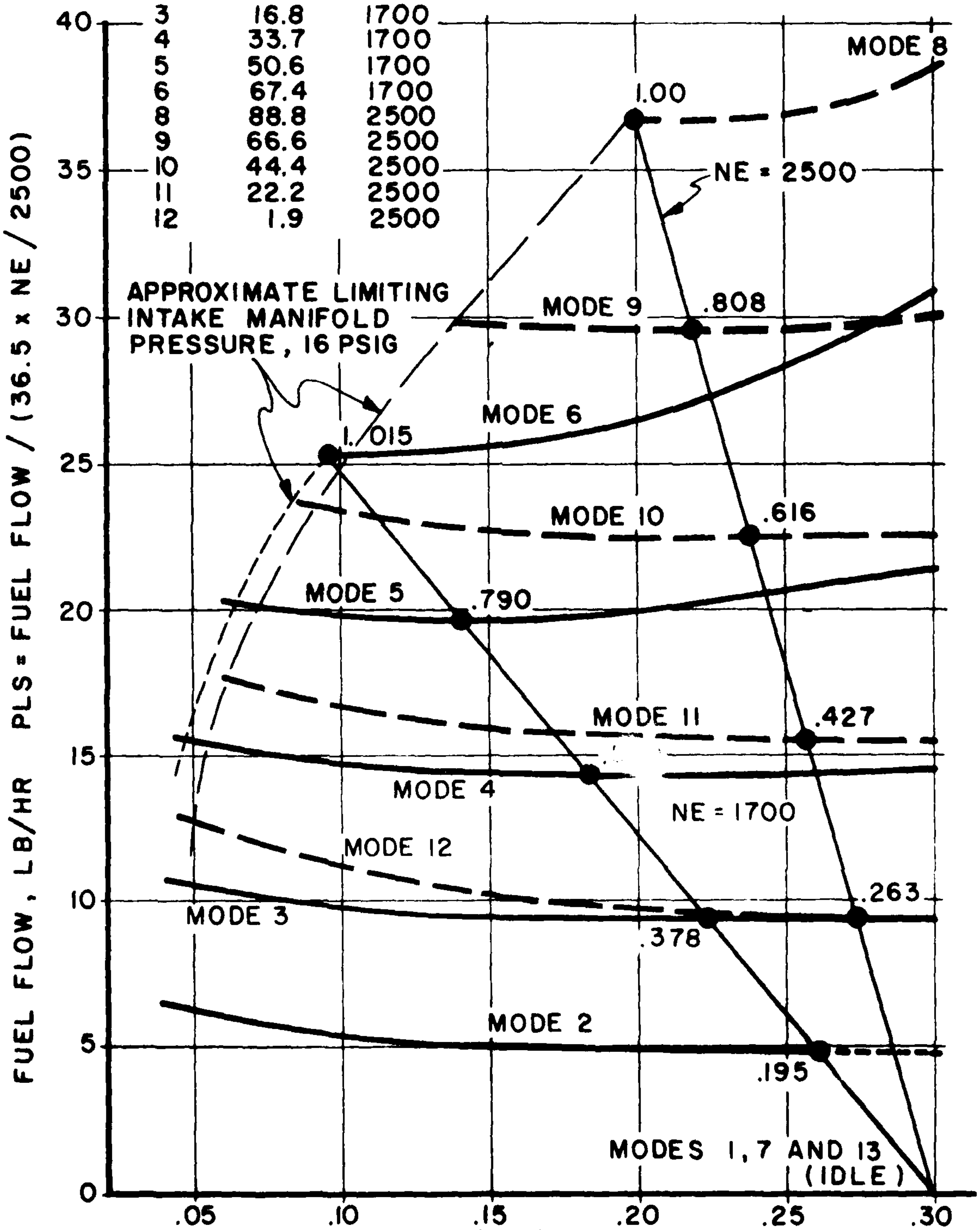
TABLE III - Calculated and measured BSFC values for VATN turbocharger

| Engine Speed (rpm) | Load (ft lb) | BSFC (lb/hp-hr) meas | calc | error |
|---|---|---|---|---|
| 2500 | 194 | .400 | .4303 | +7.6% |
| 2500 | 195 | .400 | .4093 | +2.3% |
| 2500 | 98 | .479 | .4981 | +4.0% |
| 2500 | 97 | .500 | .5105 | +2.1% |
| 1500 | 216 | .379 | .4181 | +10.3% |
| 1500 | 216 | .377 | .3870 | +2.6% |
| 1500 | 108 | .412 | .4151 | +0.7% |
| 1500 | 108 | .407 | .4198 | +3.1% |
| 1500 | 108 | .409 | .4168 | +1.9% |
| | | | avg. = +3.8% | |

The model predicts the BSFC to be 3.8% too high for the VATN unit and 1.6% high for the fixed area unit. The additional error for the VATN turbocharger may be due to the volumetric efficiency algorithm not properly accounting for the difference between intake and exhaust manifold pressure. This, inturn, causes the calculated air/fuel ratio to be in error. Many of the calculation procedures depend on air/fuel ratio, including the indicated thermal efficiency calculation.

FIGURE 25-

CALCULATED 4239T DEERE ENGINE FUEL FLOW FOR 13 MODE FEDERAL DIESEL EMISSIONS CYCLE




| MODE | HP | RPM |
|---|---|---|
| 1,7 & 13 | 0 | 850 |
| 2 | 1.3 | 1700 |
| 3 | 16.8 | 1700 |
| 4 | 33.7 | 1700 |
| 5 | 50.6 | 1700 |
| 6 | 67.4 | 1700 |
| 8 | 88.8 | 2500 |
| 9 | 66.6 | 2500 |
| 10 | 44.4 | 2500 |
| 11 | 22.2 | 2500 |
| 12 | 1.9 | 2500 |

VG = VANE THROAT DIMENSION, IN.

$$VG = PLS\ [.3125(NE/2500) - .4125] + .300$$

OR

$$VG = \left(\frac{\text{FUEL FLOW}}{36.5 \times NE/2500}\right)[.3125\ (NE/2500) - .4125] + .300$$

FIGURE 26-
CALCULATED 4239T DEERE ENGINE
HYDROCARBON EMISSIONS FOR 13 MODE FEDERAL
DIESEL EMISSIONS CYCLE

| MODE | HP | RPM |
|---|---|---|
| 1,7 & 13 | 0 | 850 |
| 2 | 1.3 | 1700 |
| 3 | 16.8 | 1700 |
| 4 | 33.7 | 1700 |
| 5 | 50.6 | 1700 |
| 6 | 67.4 | 1700 |
| 8 | 88.8 | 2500 |
| 9 | 66.6 | 2500 |
| 10 | 44.4 | 2500 |
| 11 | 22.2 | 2500 |
| 12 | 1.9 | 2500 |

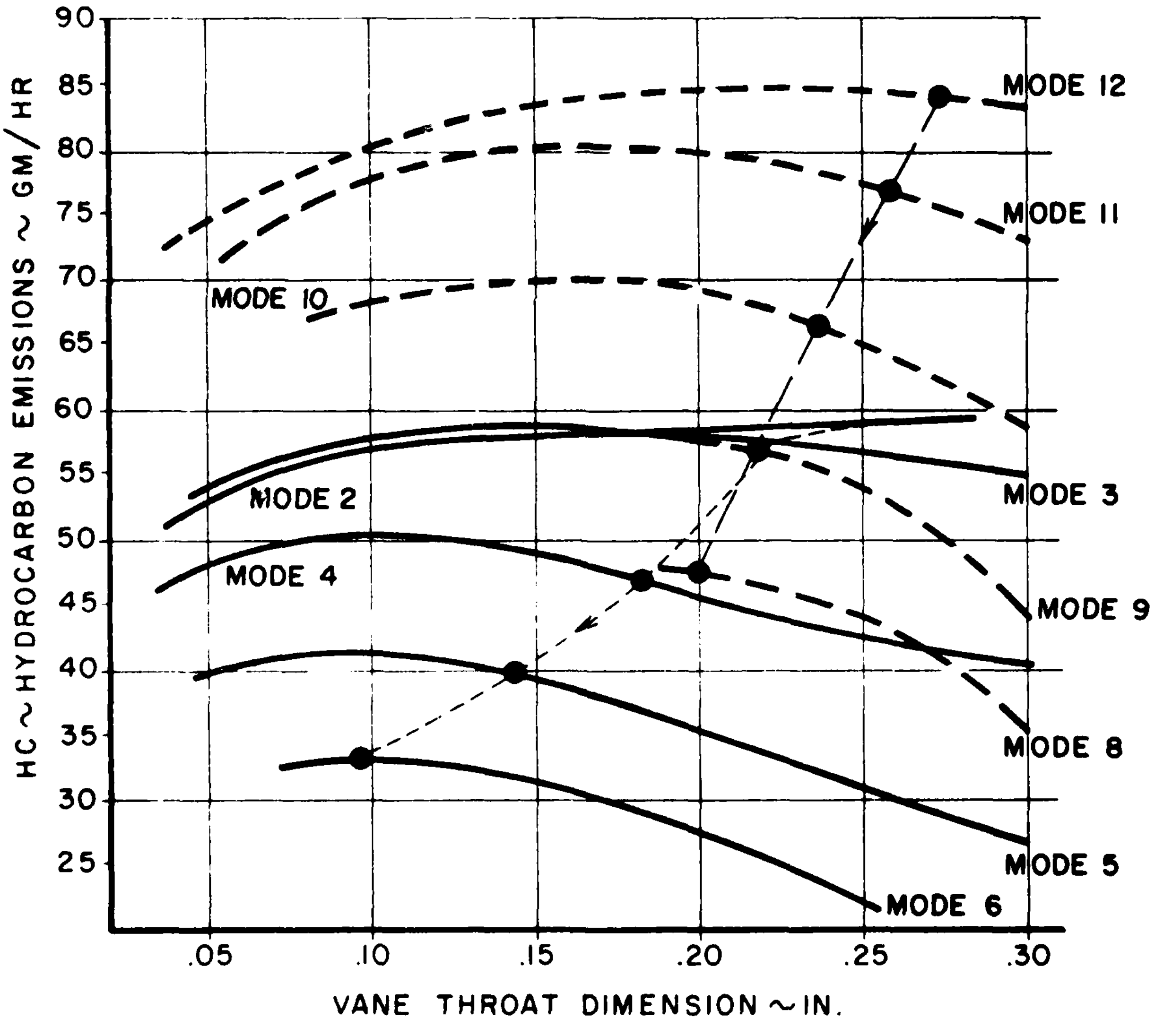


FIGURE 27-

CALCULATED 4239T DEERE ENGINE

CARBON MONOXIDE EMISSIONS FOR 13 MODE FEDERAL

DIESEL EMISSIONS CYCLE

| MODE | HP | RPM |
|---|---|---|
| 1,7 & 13 | 0 | 850 |
| 2 | 1.3 | 1700 |
| 3 | 16.8 | 1700 |
| 4 | 33.7 | 1700 |
| 5 | 50.6 | 1700 |
| 6 | 67.4 | 1700 |
| 8 | 88.8 | 2500 |
| 9 | 66.6 | 2500 |
| 10 | 44.4 | 2500 |
| 11 | 22.2 | 2500 |
| 12 | 1.9 | 2500 |

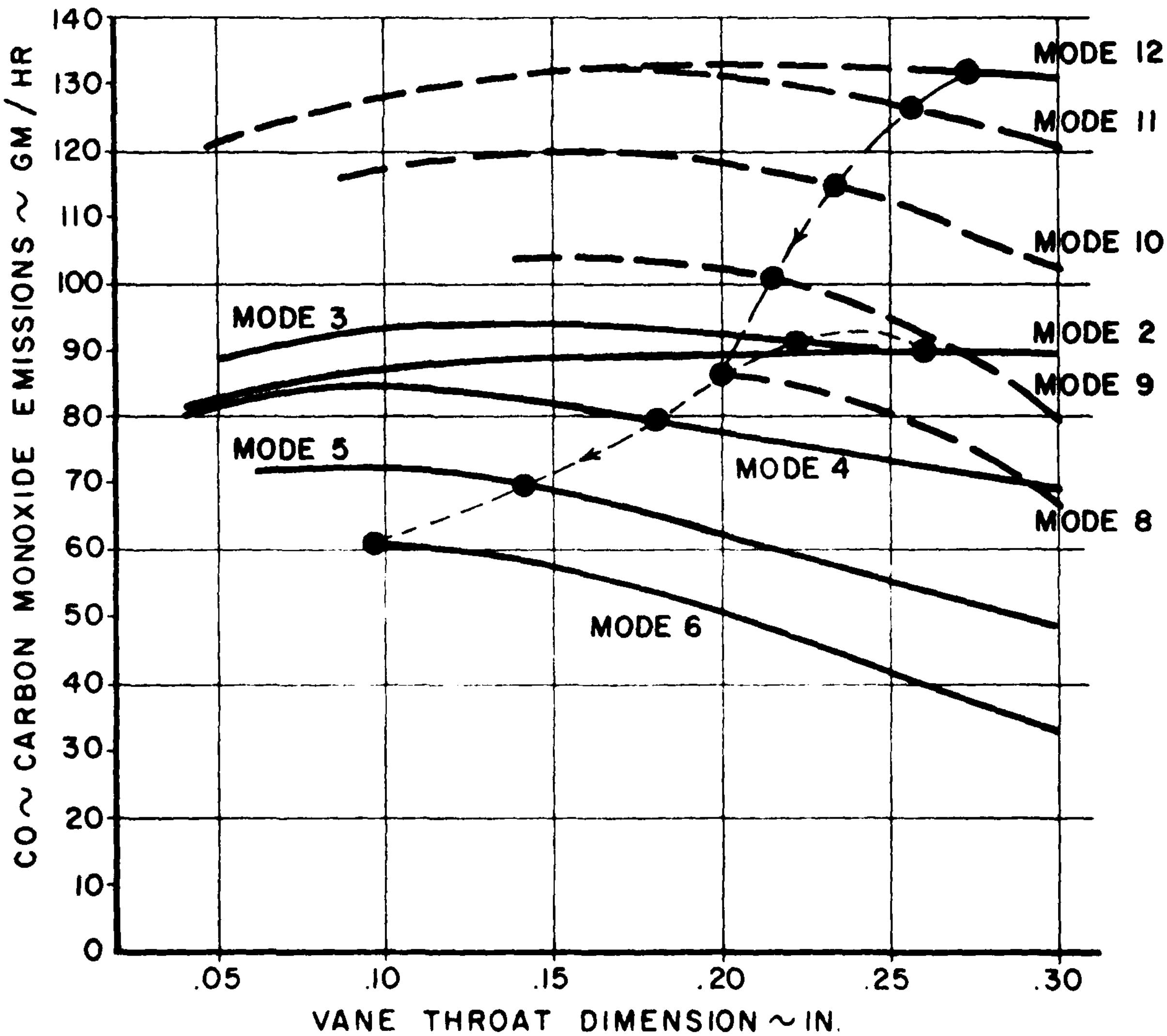


FIGURE 28- CALCULATED 4239T DEERE ENGINE OXIDES OF NITROGEN FOR 13 MODE FEDERAL DIESEL EMISSIONS CYCLE

| MODE | HP | RPM |
|---|---|---|
| 1,7 & 13 | 0 | 850 |
| 2 | 1.3 | 1700 |
| 3 | 16.8 | 1700 |
| 4 | 33.7 | 1700 |
| 5 | 50.6 | 1700 |
| 6 | 67.4 | 1700 |
| 8 | 88.8 | 2500 |
| 9 | 66.6 | 2500 |
| 10 | 44.4 | 2500 |
| 11 | 22.2 | 2500 |
| 12 | 1.9 | 2500 |

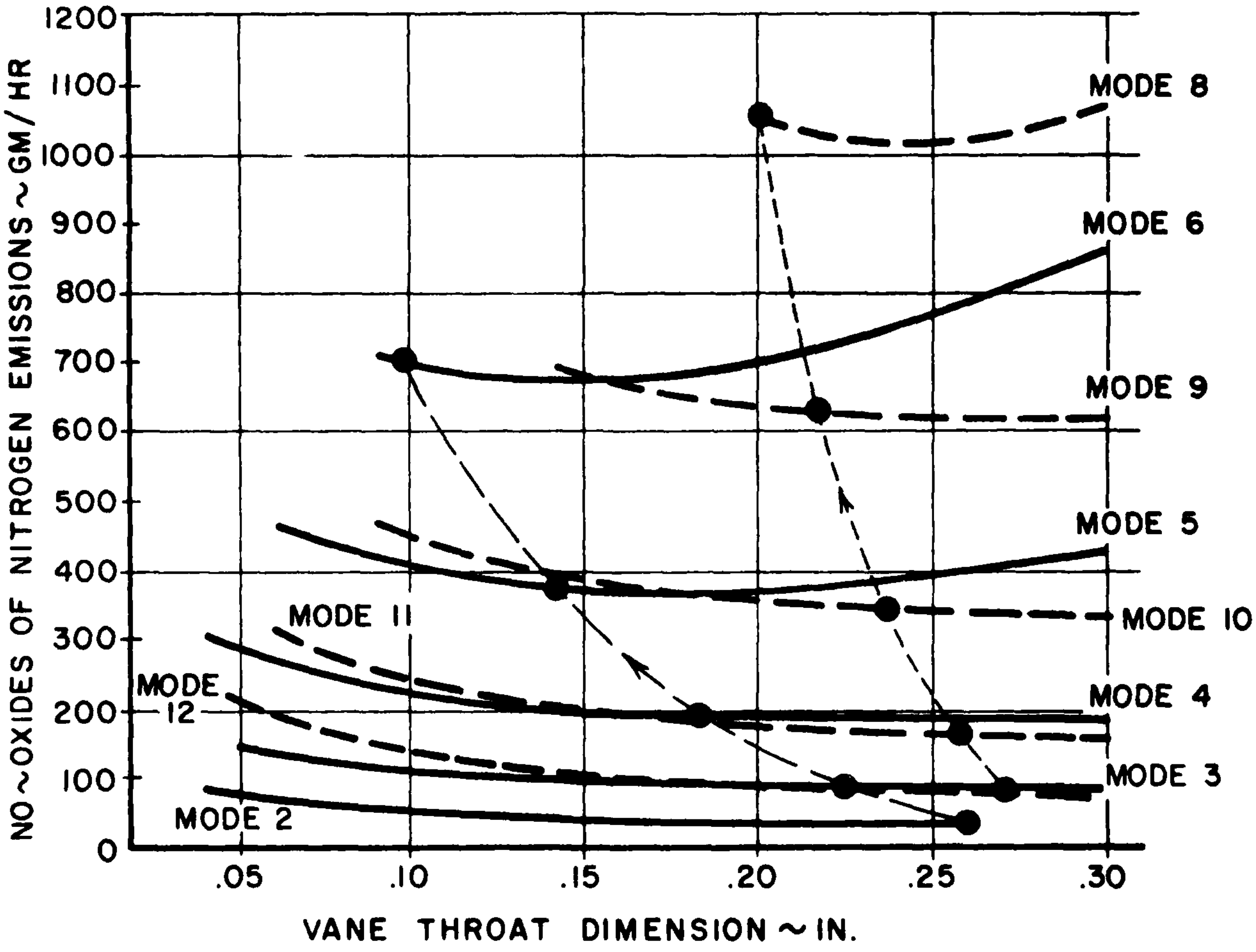
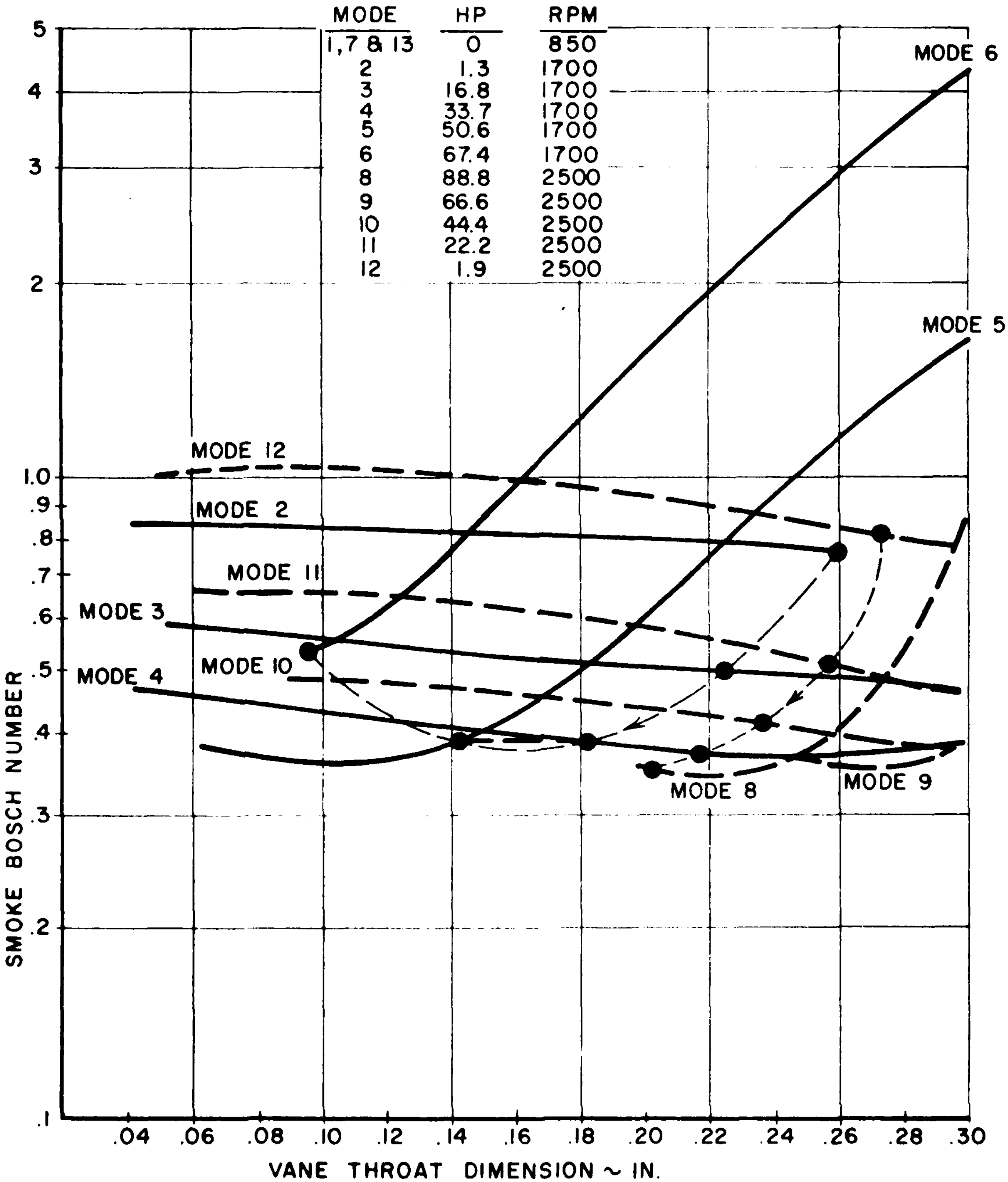


FIGURE 29- CALCULATED 4239T DEERE ENGINE SMOKE BOSCH NUMBER FOR 13 MODE FEDERAL DIESEL EMISSIONS CYCLE



## MODEL APPLICATION

### 13 Mode Federal Diesel Emissions Cycle

The math model described above was used to generate John Deere 4239T engine fuel consumption, smoke, and emissions data for the 13 operating modes of the federal diesel emissions cycle. The mode definitions and calculation procedures were taken from the 1981 SAE Handbook, pages 25.20 and 25.21 (SAE J1003). At each of the 13 modes the model was executed at various vane throat values. The maximum firing pressure limit was approximated by constraining the intake manifold pressure to values less than 16 psig. Figure 25 presents the calculated fuel flow rates for each of the modes as a function of vane throat. The power output and engine speed are also called out in figure 25 for each mode. Figures 26, 27, and 28 show unburned hydrocarbons, carbon monoxide, and oxides of nitrogen in a similar fashion to figure 25. Bosch smoke number is shown in figure 29.

### Control Strategy

A control strategy was defined for the 4239T engine operating over the 13 mode federal diesel cycle. To define the control operation, it was assumed that fuel flow per revolution is proportional to throttle position. A control schedule was derived which would define the desired vane throat as a function of engine speed and throttle position.

$$VT = PLS\ (0.3125\ (NE/NEmax) - 0.4125) + 0.300$$

where:

VT = vane throat - inches

PLS = throttle position as a fraction of full travel

NE = engine speed - rpm

NEmax = maximum rated engine speed - rpm

This control schedule was thought to be relatively simple, involving only two independent variables: engine speed and throttle position. The mathematical function was derived so as to pass the control schedule through, or near, the minimum fuel flow rate points for each mode. The resulting operating lines are shown in figures 25 through 29. Weighted average values of brake specific fuel consumption and emissions were calculated using the aforementioned SAEJ1003 procedure.

The mode operating conditions are shown in Table IV below.

Table IV - Speed-Load Schedule of 13-Mode Federal
Diesel Emission Cycle

| Mode | Speed | Torque |
|---|---|---|
| 1 | IDLE | -- |
| 2 | S | 0.02 x Tm |
| 3 | S | 0.25 x Tm |
| 4 | S | 0.50 x Tm |
| 5 | S | 0.75 x Tm |
| 6 | S | Tm |
| 7 | IDLE | -- |
| 8 | Sm | T |
| 9 | Sm | 0.75 x T |
| 10 | Sm | 0.50 x T |
| 11 | Sm | 0.25 x T |
| 12 | Sm | 0.02 x T |
| 13 | IDLE | -- |

where:

Tm - Rated Torque

Sm - Rated Speed

T - Highest Torque at Rated Speed

S - Highest Speed at Rated Torque

Table V - lists the emissions and fuel consumption data calculated for the Aerodyne turbocharger controlled to the schedule shown in figures 25 through 28.

Table V - 13 Mode Emissions Calculated For Aerodyne Turbocharger With Controller

For Idle Modes (1, 7 & 13) Mass Flows are:
HC = 28.7 GM/HR CO = 42.73 GM/HR NO2 = 12.04 GM/HR
Fuel = 1.76 LB/HR

Brake Specific Emissions And Fuel Consumption For Non-Idle Modes

| Mode | BSHC GM/HP-HR | BSCO GM/HP-HR | BSNO2 GM/HP-HR | BSFC LB/HP-HR |
|---|---|---|---|---|
| 2 | 23.74 | 36.40 | 15.04 | 2.071 |
| 3 | 3.38 | 5.46 | 4.96 | 0.558 |
| 4 | 1.40 | 2.37 | 5.54 | 0.428 |
| 5 | 0.80 | 1.42 | 7.24 | 0.389 |
| 6 | 0.53 | 0.96 | 9.99 | 0.375 |
| 8 | 0.47 | 0.87 | 12.84 | 0.415 |
| 9 | 0.80 | 1.42 | 9.88 | 0.448 |
| 10 | 1.50 | 2.57 | 7.64 | 0.508 |
| 11 | 3.27 | 5.39 | 7.52 | 0.690 |
| 12 | 18.58 | 29.29 | 18.67 | 2.281 |
| Weighted Avg Values: | | | | |
| | 1.60 | 2.65 | 9.47 | 0.510 |

The math model was also used to calculate the same data for the T04 turbocharger. Table VI shows the results of the calculations. Table VII lists the measured 13 mode data for the T04 turbocharger. This data was measured at Southwest Research Institute as part of the previous contract.

Table VI - 13 Mode Emissions Calculated For T04 Turbocharger

For Idle Modes (1, 7 & 13) Mass Flows Are:

HC = 28.7 GM/HR CO = 42.73 GM/HR NO2 = 12.04 GM/HR

Fuel = 1.76 LB/HR

Brake Specific Emissions And Fuel Consumption For Non-Idle Modes

| Mode | BSHC GM/HP-HR | BSCO GM/HP-HR | BSNO2 GM/HP-HR | BSFC LB/HP-HR |
|---|---|---|---|---|
| 2 | 24.82 | 36.80 | 15.04 | 2.091 |
| 3 | 3.46 | 5.58 | 4.79 | 0.561 |
| 4 | 1.35 | 2.31 | 5.29 | 0.432 |
| 5 | 0.70 | 1.25 | 7.16 | 0.403 |
| 6 | 0.41 | 0.77 | 10.11 | 0.407 |
| 8 | 0.48 | 0.89 | 12.66 | 0.418 |
| 9 | 0.80 | 0.80 | 9.85 | 0.451 |
| 10 | 1.46 | 2.51 | 8.08 | 0.515 |
| 11 | 3.35 | 5.51 | 7.76 | 0.696 |
| 12 | 18.74 | 29.55 | 20.15 | 2.323 |
| Weighted Avg Values: | | | | |
| | 1.57 | 2.50 | 9.49 | 0.520 |

Table VII-13 Mode Emissions Measured For T04 Turbocharger

For Idle Modes (1, 7 & 13) Mass Flows Are:
HC = 19.65 GM/HR  CO = 33.73 GM/HR  NO2 = 12.12 GM/HR
Fuel = 1.76 LB/HR

Brake Specific Emissions And Fuel Consumption For Non-Idle Modes

| Mode | BSHC GM/HP-HR | BSCO GM/HP-HR | BSNO2 GM/HP-HR | BSFC LB/HP-HR |
|---|---|---|---|---|
| 2 | 33.17 | 55.96 | 16.72 | 4.054 |
| 3 | 2.25 | 3.66 | 4.61 | 0.562 |
| 4 | 0.99 | 1.09 | 5.56 | 0.431 |
| 5 | 0.71 | 0.65 | 7.78 | 0.396 |
| 6 | 0.45 | 1.21 | 14.72 | 0.393 |
| 8 | 0.34 | 1.15 | 11.24 | 0.418 |
| 9 | 0.26 | 0.73 | 8.34 | 0.449 |
| 10 | 1.82 | 1.27 | 5.49 | 0.515 |
| 11 | 1.98 | 3.43 | 5.32 | 0.717 |
| 12 | 29.44 | 70.56 | 19.98 | 5.526 |
| Weighted Avg Values: | 1.16 | 2.00 | 9.28 | 0.522 |

By comparing corresponding values in Table VI & VII an assessment of how well the math model compares to measured values can be made for the fixed area turbocharger. The worst agreement was between calculated and measured BSHC values; the best was BSFC. Also, the trends of all the parameters agree rather well with the measured data. A relative comparison between the Aerodyne turbocharger, operating to the previously discussed control schedule, and the T04 can be made from Tables V and VI. As shown in section III, the engine test data indicated an average improvement of 4% in BSFC of the Aerodyne turbocharger as compared to the T04. On the other hand, the math model overestimates fuel flow by 2% for the VATN unit as compared to the T04. Therefore, the calculated "13 mode" BSFC values only show a 2% improvement rather than the expected 4%. The BSHC is higher for the VATN turbocharger while BSCO and $BSNO_2$ are reduced. An overall emissions comparison is sometimes made using the sum of BSHC and $BSNO_2$. This value is essentially the same for both turbochargers. By comparing calculated results it can be concluded that the simple control schedule used for the VATN turbocharger will give improved fuel economy as compared to the fixed area T04.

Much more complicated control strategies could be developed which would take into consideration the engines coolant temperature and barometric conditions. This approach is beyond the scope of this contract, but could give additional improvements.

A control system was built that sensed throttle position and engine speed. The analog circuit output was a "desired" position to a stepping motor which was connected to the VATN control rod. Bench tests of the unit showed that the stepping motor could not respond fast enough. Full travel required 3.0 seconds which was too long a time to justify any further development expenses. Therefore, the hardware phase was stopped. It is felt that the best way to control the VATN system is through a pneumatic driver (piston and spring) with the difference in pressure across the piston being a "leak" to one side of the piston. The piston would be sized to give the proper force to the VATN control rod.

<u>Driving Cycle Simulation (LA4)</u>

In order to use the new math model to estimate results of an automobile operating over the federal driving cycle, it was necessary to generate a math model which would calculate the engine load and speed. Also, an abreviation of the full 1320 seconds was necessary in order to make the problem manageable. Southwest Research Institute provided an approximation to the LA4 driving cycle. The approximation was made up of nine modes. A VW diesel Rabbitt was chosen as the automobile. Physical characteristics of the automobile and drive line were taken from "Road and Track" magazine and are as follows:

- frontal area = 16.575ft$^2$
- weight = 2200 lbm
- max engine speed = 5200 rpm
- gear ratios were 3.76, 1.94, 1.29, and .76 for 1st through 5th gear
- engine speed/car velocity ratio (rpm/mph) of 46

The N/V value in the open literature is 46. A value of 35 was used for this analysis. It was felt that this respresents the lowest value reasonable. Even this value requires a very responsive turbocharged engine. A description of the nine modes and associated engine operating conditions is given in Table VIII.

The performance of three engines was estimated using the new math model and the speed and power requirements shown in Table VIII. Engine A represents the current 1.47 liter engine turbocharged to a maximum intake manifold pressure of 1.82 atmosphere absolute pressure, a value assumed to represent contemporary automotive diesel engine. Engine B is a normally aspirated, 2.62 liter engine. Engine C has a displacement of 1.08 liters. The displacement for engines B and C were determined by requiring the power output, at mode 9 conditions, to be equal to that of engine A. For this determination all three engines were assumed to have an air/fuel ratio of 20. Engine C reflects future diesel engine intake manifold pressure level; a value of 3.18 atmosphere (abs) was selected. The turbine vane position controller was assumed to be the same as the one previously used for the "13 mode" analysis. Figure 30 shows the brake specific fuel consumption (BSFC) as a function of vane throat for each of the nine modes approximating the LA4 driving cycle. Similar data for engine C is shown in figure 31. The "X" symbol indicates the vane position to which the controller moves for each mode. Recall this vane position (throat) is dependent on throttle position and engine speed. Table IX, X and XI list the vane position (VG), BSFC, horsepower, engine speed, and fraction of total fuel usage (%fuel) for each of the nine modes for engine A, B, and C respectively. These tables also show the overall miles per gallon, mpg. It can be seen that the economy is improved 51 percent by replacing a normally aspirated, 2.62 liter engine with a turbocharged engine of equivalent performance. An additional 14 percent improvement can be realized by further reducing the engine size and appropriately increasing the boost level. This estimated performance for engine C also included the effect on indicated thermal efficiency of reducing the compression ratio from 23 to 12. This was done to maintain a reasonable peak firing pressure. This factor was determined from Taylor's "The Internal Combustion Engine in Theory and Practice".

Generator Set Application

In the past, turbocharged diesel engines have not been used to drive Army generator sets because of the requirement that the gen set be able to go from zero to full load while maintaining frequency. Turbocharger "lag" was the source of the problem. The VATN feature can eliminate this problem. This allows smaller, turbocharged diesel engines to replace normally aspirated engines which, inturn, will result in reduced fuel consumption. Using electrical generator efficiency data and fuel consumption data supplied by the Army, the math model was used to estimate potential fuel savings which could be realized by replacing the six cylinder, normally aspirated, 298 CID, diesel engine used to drive a 30KW generator set with a four cylinder, turbocharged, 226 CID, engine. A 0.95 multiplying factor on the indicated thermal efficiency and a 1.10 factor on friction loss enabled the model to predict the current 15KW and 30KW fuel consumption values as measured during the Mil. std. 705 test cycle. Mil. std. 705 duty cycle is as follows:

4 hours at zero load

24 hours at 25% load (15.5hp)

24 hours at 50% load (27.2hp)

24 hours at 75% load (38.2hp)

24 hours at 100% load (49.1hp)

Ambient conditions were 60°F and 29.92 "Hg". The engine speed is a constant 1800 rpm. The calculated and measured fuel usage values were 126.2 gal and 130.0 gal for the 15KW unit and 227.4 gal and 222.9 gal for the 30KW unit. In terms of error, the 15KW error was -2.9% and the 30KW error was +2.0%.

A 226 CID, 4 cylinder engine was selected to replace the 6 cylinder engine because the engine has been designed to be turbocharged. An air/fuel ratio of 28 was assumed at full power. It was felt that this is a conservative value which would give good BSFC and no smoke. The resulting compressor pressure ratio was 1.36. Three control strategies were assumed. Control strategy A assumed that the turbocharger pressure ratio, and therefore speed, would be held constant at 1.36. Strategy B held the pressure ratio at 1.36 down to the 25 percent load point. At loads below 25 percent, the vanes were held fixed. It was felt that this would improve the adverse pressure difference across the engine at zero load. The third strategy, C, was similar to B except that the vanes were held fixed from 50% load down to no-load. Table XII compares the fuel consumption of each of the three strategies for the Mil. std. 705 duty cycle. In order to assess the acceptability of allowing the turbocharger speed to drop at low loads (strategies B and C), an instanteous air/fuel ratio was calculated using the full load fuel flow rate and the no-load air flow rate. This should be the worst condition possible. Table XII also lists these instanteous values and the engine pressure difference which is exhaust manifold pressure less intake manifold pressure. From these results it is felt that the Aerodyne VATN turbocharger could be employed to reduce the 30KW gen set fuel consumption by 8 to 10 percent of current values. Also the turbocharger vanes could remain in a fixed position below 25 to 50% load without adversely affecting the gen set response.

Table VIII - Nine mode approximation to LA4 driving cycle

| Mode # | Gear | Vel mph | Accel mph/sec | Power hp | Eng spd rpm |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 850 |
| 2 | 2 | 20 | 0 | 1.475 | 1786 |
| 3 | 2 | 25 | 0 | 2.148 | 2233 |
| 4 | 3 | 30 | 0 | 3.023 | 1782 |
| 5 | 4 | 35 | 0 | 4.141 | 1563 |
| 6 | 4 | 45 | 0 | 7.269 | 2010 |
| 7 | 4 | 55 | 0 | 11.856 | 2456 |
| 8 | 1 | 15 | 2.5 | 12.108 | 2597 |
| 9 | 2 | 25 | 2.5 | 20.720 | 2233 |

FIGURE 30-
ENGINE A BSFC AS A FUNCTION
OF VANE THROAT FOR LA4

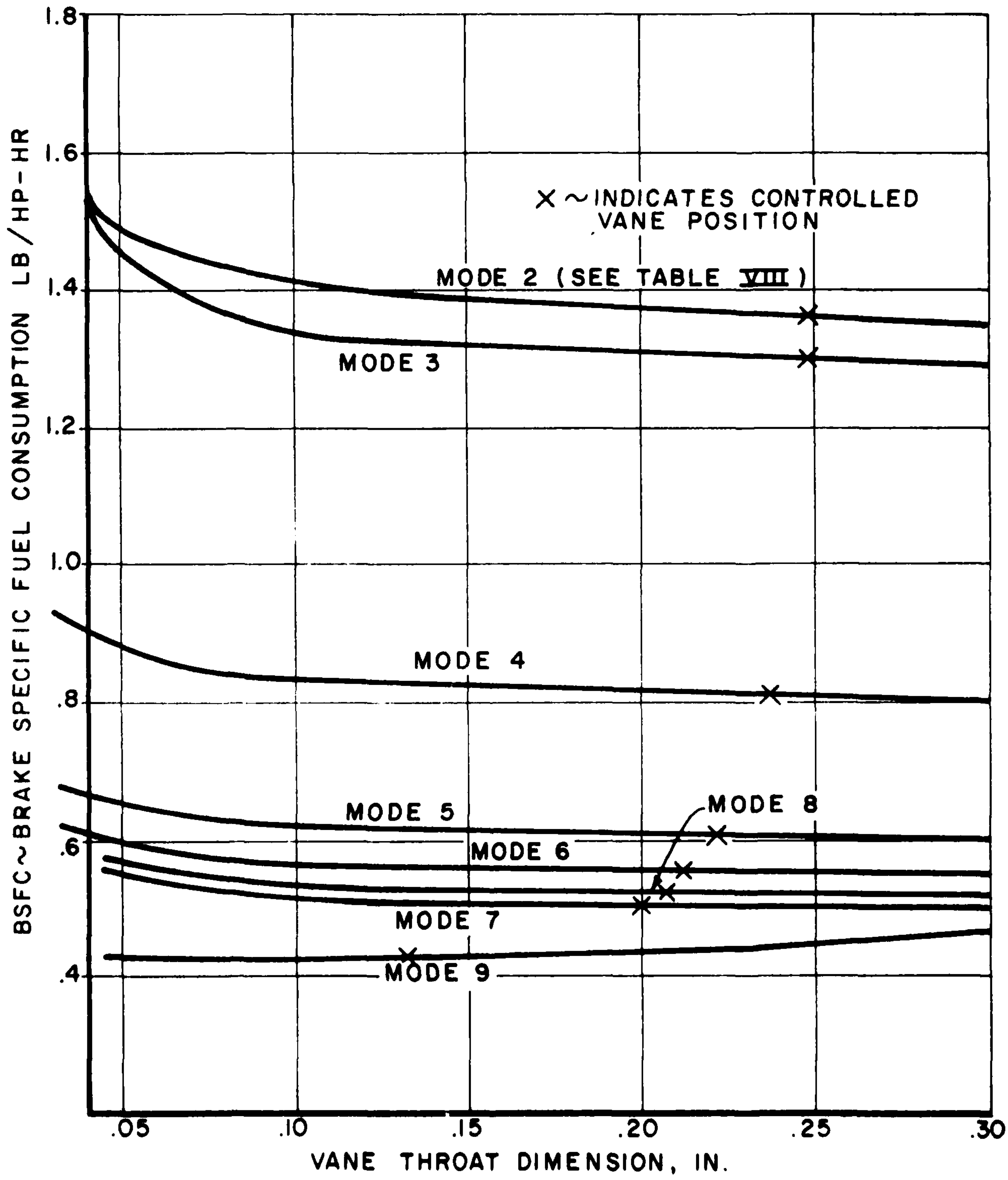


FIGURE 31-

ENGINE C BSFC AS A FUNCTION OF VANE THROAT FOR LA4

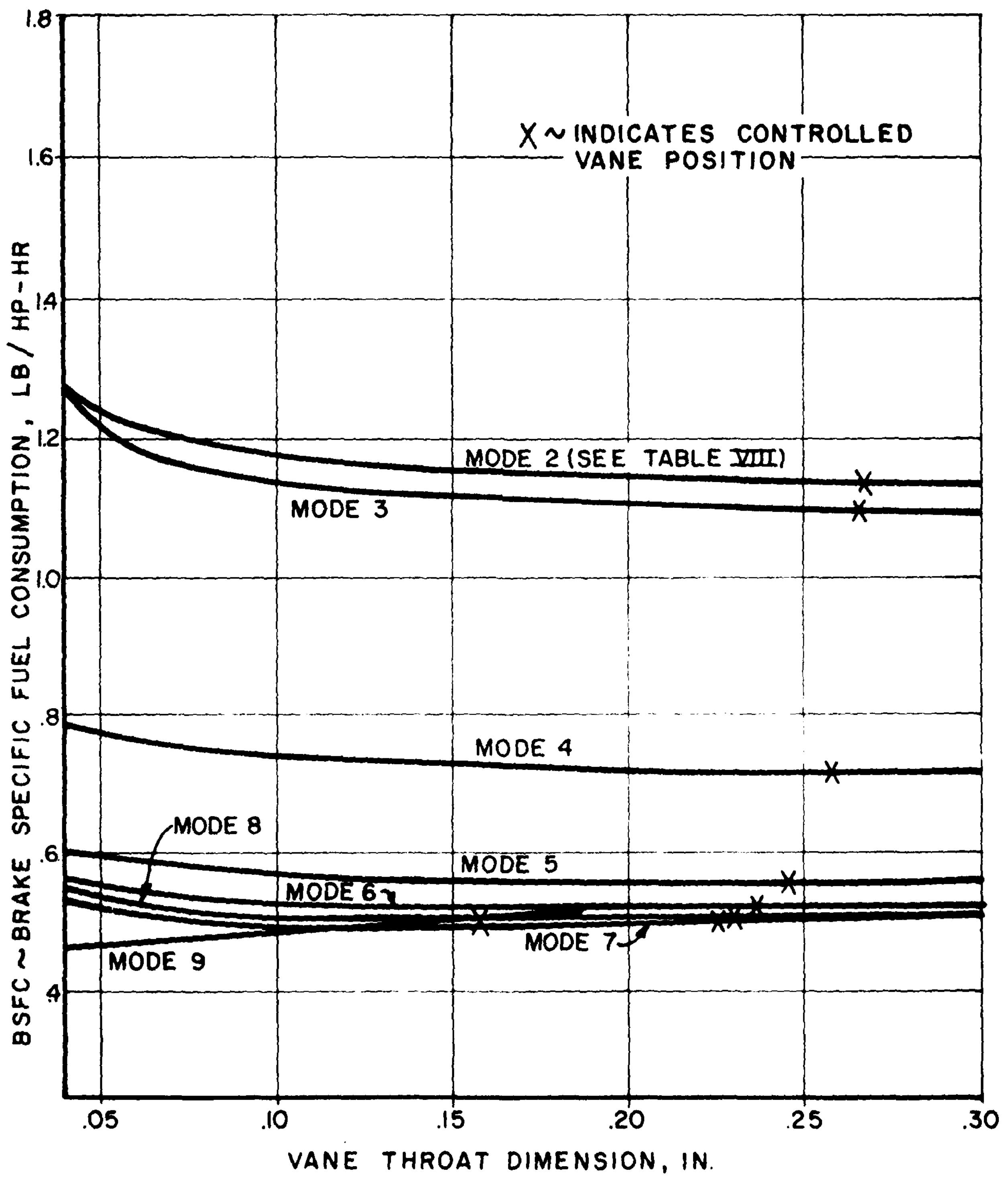


Table IX - Engine A LA4 fuel usage

| Mode | VG | BSFC | HP | RPM | %FUEL |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 1.000 | 0.000 | 0.078 |
| 2 | 0.249 | 1.367 | 1.475 | 1789.950 | 0.047 |
| 3 | 0.248 | 1.303 | 2.148 | 2237.410 | 0.224 |
| 4 | 0.237 | 0.815 | 3.023 | 1785.300 | 0.072 |
| 5 | 0.223 | 0.612 | 4.141 | 1566.170 | 0.037 |
| 6 | 0.213 | 0.553 | 7.269 | 2013.720 | 0.015 |
| 7 | 0.202 | 0.510 | 11.856 | 2461.180 | 0.129 |
| 8 | 0.206 | 0.525 | 12.108 | 2601.870 | 0.206 |
| 9 | 0.134 | 0.430 | 28.720 | 2237.410 | 0.192 |

MPG= 48.593 Total Fuel= .148169 GAL N/V=35

Table X - Engine B LA4 fuel usage

| Mode | VG | BSFC | HP | RPM | %FUEL |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 1.000 | 0.000 | 0.097 |
| 2 | 0.236 | 2.386 | 1.475 | 1789.958 | 0.054 |
| 3 | 0.235 | 2.283 | 2.148 | 2237.410 | 0.259 |
| 4 | 0.228 | 1.308 | 3.023 | 1785.300 | 0.076 |
| 5 | 0.218 | 0.908 | 4.141 | 1566.170 | 0.036 |
| 6 | 0.210 | 0.799 | 7.269 | 2013.720 | 0.015 |
| 7 | 0.202 | 0.717 | 11.856 | 2461.100 | 0.119 |
| 8 | 0.205 | 0.745 | 12.108 | 2601.870 | 0.193 |
| 9 | 0.158 | 0.514 | 20.720 | 2237.410 | 0.152 |

MPG= 32.0349 Total Fuel= .224755 GAL N/V=35

Table XI - Engine C LA4 fuel usage

| Mode | VG | BSFC | HP | RPM | %FUEL |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 1.000 | 0.000 | 0.064 |
| 2 | 0.268 | 1.098 | 1.475 | 1789.950 | 0.041 |
| 3 | 0.267 | 1.054 | 2.148 | 2237.410 | 0.196 |
| 4 | 0.258 | 0.698 | 3.023 | 1785.300 | 0.066 |
| 5 | 0.246 | 0.545 | 4.141 | 1566.170 | 0.036 |
| 6 | 0.237 | 0.512 | 7.269 | 2013.720 | 0.016 |
| 7 | 0.226 | 0.488 | 11.856 | 2461.180 | 0.134 |
| 8 | 0.230 | 0.493 | 12.108 | 2601.870 | 0.209 |
| 9 | 0.150 | 0.494 | 20.720 | 2237.410 | 0.239 |

MPG= 52.589 Total Fuel= .136911 GAL N/V=35

Table XII - Comparison of control strategies with current 30KW gen set - Mil. std. 705 duty cycle.

| | Strategy | | | Current |
|---|---|---|---|---|
| | A | B | C | 298 |
| No-load fuel usage, gal | 3.0 | 2.88 | 2.84 | 3.58 |
| 25% load fuel usage, gal | 32.40 | 32.40 | 32.20 | 37.09 |
| 50% load fuel usage, gal | 44.19 | 44.19 | 44.19 | 49.44 |
| 75% load fuel usage, gal | 55.67 | 55.67 | 55.67 | 61.32 |
| 100% load fuel usage, gal | 69.36 | 69.36 | 69.36 | 75.93 |
| total fuel gal | 204.62 | 204.50 | 204.26 | 227.40 |
| Instanteous no-load A/F | 28.1 | 25.9 | 24.8 | |
| No-load engine pressure difference, psig. | -1.42 | -.84 | -.69 | |

## VI RECOMENDATION

The Aerodyne turbocharger has been developed to the point where the device is ready to be tested in an actual application environment. Also, the analytical study described herein indicated that the turbocharger can satisfy military 30KW DED generator set response requirements and reduce fuel consumption by 8 to 10%. Therefore, it is recommended that the six cylinder diesel engine currently used to drive the 30KW gen set be replaced by a reduced size diesel engine turbocharged with the Aerodyne turbocharger. The purpose of this unit would be to demonstrate fuel savings and compliance with Army generator set performance standards. This unit could also be used for initial durability testing.

APPENDIX

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.52

| Rdg#/Hr:Mn | 1/11:37 | 2/12:33 | 3/12:36 | 4/13:04 | 5/13:19 |
|---|---|---|---|---|---|
| Engine Speed (RPM) | 1461 | 1493 | 1511 | 1008 | 1004 |
| Torque (ft-#) | 2.4 | 250.7 | 252.1 | 47.9 | 96.5 |
| Horsepower (HP) | 0.7 | 71.3 | 72.5 | 9.2 | 18.4 |
| sfc (#/HP-hr) | 0.899 | 0.008 | 0.008 | 0.519 | 0.415 |
| Air/Fuel Ratio | 735.17 | 1072.37 | 1104.07 | 54.83 | 34.09 |
| Dry Air/Fuel Ratio | 723.36 | 1053.39 | 1084.14 | 53.83 | 33.46 |
| Rel Humidity (%) | 47 | 47 | 47 | 47 | 47 |
| Dry Bulb Temp (R) | 555.0 | 558.0 | 558.6 | [illegible] | 559.6 |
| Engine delta P (psi) | -1.77 | 0.72 | 2.23 | [illegible] | -0.17 |
| Air Rate (#/hr) | 441.1 | 632.7 | 651.4 | [illegible] | 261.0 |
| Fuel Rate (#/hr) | 0.600 | 0.590 | 0.590 | [illegible] | 7.656 |
| Fuel time (sec) | 60.0 | 61.0 | 61.0 | 754.2 | 470.2 |
| Fuel Temp (R) | 549.5 | 566.3 | 564.5 | 569.3 | 573.1 |
| Crank Case Oil Temp (R) | 574.0 | 673.1 | 679.2 | 659.8 | 663.0 |
| | | | | | |
| Compressor Pressure Ratio | 1.153 | 1.886 | 2.066 | 1.012 | 1.042 |
| Corrected Flow (CFM) | 101.6 | 147.2 | 152.0 | 60.3 | 60.3 |
| Corrected Flow (#/sec) | 0.129 | 0.188 | 0.194 | 0.077 | 0.077 |
| Compressor Efficiency (%) | 71.8 | 75.3 | 64.2 | 9.1 | 19.2 |
| Compr Eff w/o .0008HT(%) | 84.8 | 83.1 | 69.0 | 27.1 | 54.1 |
| Inlet Temp (R) | 554.6 | 559.1 | 559.6 | 560.5 | 561.5 |
| Discharge Temp (R) | 586.8 | 706.8 | 760.5 | 582.4 | 596.1 |
| Inlet Press (psia) | 14.383 | 14.296 | 14.254 | 14.447 | 14.437 |
| Discharge Press (psia) | 16.590 | 26.964 | 29.448 | 14.627 | 15.043 |
| Corrected Speed (RPM/√O) | 45134 | 90876 | 97893 | 22202 | 28757 |
| Actual Speed (RPM) | 46670 | 94350 | 101680 | 23080 | 29920 |
| | | | | | |
| Turbine Expansion Ratio | 1.279 | 1.861 | 1.932 | 1.037 | 1.052 |
| Corrected Speed (rpm) | 38332 | 56697 | 59337 | 17520 | 20716 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | -0.250 | -0.250 | -0.250 | 0.290 | 0.290 |
| Corrected Flow (#/sec) | 0.120 | 0.164 | 0.168 | 0.096 | 0.104 |
| Turbine Efficiency (%-meas T) | 98.7 | 99.5 | 90.4 | 309.9 | 288.4 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 80.8 | 71.4 | 84.8 | 300.2 | 271.7 |
| U/V' | 0.670 | 0.637 | 0.648 | 0.785 | 0.784 |
| Load Coef | 1.099 | 1.227 | 1.075 | 2.516 | 2.347 |
| Inlet Temp (R) | 768.9 | 1436.4 | 1523.1 | 900.1 | 1082.0 |
| Discharge Temp (R) | 717.8 | 1219.3 | 1304.4 | 872.0 | 1038.9 |
| Inlet Press (psia) | 18.357 | 26.243 | [illegible] | 14.966 | 15.210 |
| Discharge Press (psia) | 14.354 | 14.101 | [illegible] | 14.433 | 14.456 |
| | | | | | |
| Compressor Power (HP) | 1.13 | 8.02 | 11.53 | 0.18 | 0.30 |
| Eff-comprXEff-turb | 0.441 | 0.472 | 0.489 | 0.211 | 0.414 |
| Eff-turb from Eff-compr w/o HT | 51.97 | 56.76 | 70.79 | 77.76 | 76.60 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.48

| Rdg#/Hr:Mn | 6/13:44 | 7/13:54 | 8/14:16 | 9/14:43 | 10/14:52 |
|---|---|---|---|---|---|
| Engine Speed (RPM) | 1497 | 1508 | 1013 | 1499 | 1997 |
| Torque (ft-#) | 54.1 | 108.2 | 1.6 | 1.9 | 1.9 |
| Horsepower (HP) | 15.4 | 31.1 | 0.3 | 0.5 | 0.7 |
| sfc (#/HP-hr) | 0.503 | 0.412 | 7.152 | 6.899 | 8.143 |
| Air/Fuel Ratio | 51.15 | 32.24 | 120.53 | 107.19 | 88.66 |
| Dry Air/Fuel Ratio | 50.18 | 31.62 | 118.26 | 105.08 | 86.91 |
| Rel Humidity (%) | 47 | 47 | 47 | 47 | 47 |
| Dry Bulb Temp (R) | 560.1 | 560.8 | 559.8 | 561.3 | 561.3 |
| Engine delta P (psi) | -0.36 | 0.15 | -0.45 | -0.55 | -0.89 |
| Air Rate (#/hr) | 397.1 | 412.5 | 266.0 | 401.0 | 521.6 |
| Fuel Rate (#/hr) | 7.763 | 12.794 | 2.207 | 3.741 | 5.883 |
| Fuel time (sec) | 463.7 | 281.4 | 914.9 | 480.7 | 305.7 |
| Fuel Temp (R) | 572.5 | 573.6 | 579.4 | 575.3 | 574.9 |
| Crank Case Oil Temp (R) | 669.8 | 676.9 | 657.3 | 663.8 | 669.3 |
| | | | | | |
| Compressor Pressure Ratio | 1.050 | 1.111 | 0.997 | 1.029 | 1.051 |
| Corrected Flow (CFM) | 92.1 | 95.7 | 61.5 | 93.1 | 121.6 |
| Corrected Flow (#/sec) | 0.117 | 0.122 | 0.078 | 0.119 | 0.155 |
| Compressor Efficiency (%) | 29.6 | 39.4 | -3.3 | 26.5 | 32.5 |
| Compr Eff w/o .0008HT(%) | 51.7 | 64.0 | -7.4 | 38.9 | 43.0 |
| Inlet Temp (R) | 562.2 | 562.9 | 562.6 | 562.6 | 562.4 |
| Discharge Temp (R) | 589.0 | 606.4 | 575.7 | 579.8 | 587.2 |
| Inlet Press (psia) | 14.374 | 14.387 | 14.418 | 14.376 | 14.311 |
| Discharge Press (psia) | 15.096 | 15.979 | 14.379 | 14.787 | 15.042 |
| Corrected Speed (RPM/√O) | 31207 | 39741 | 17581 | 27336 | 36263 |
| Actual Speed (RPM) | 32490 | 41400 | 18310 | 28470 | 37760 |
| | | | | | |
| Turbine Expansion Ratio | 1.074 | 1.101 | 1.028 | 1.067 | 1.110 |
| Corrected Speed (rpm) | 23779 | 27428 | 15379 | 23470 | 29490 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.290 | 0.290 | 0.290 | 0.290 | 0.290 |
| Corrected Flow (#/sec) | 0.146 | 0.166 | 0.088 | 0.131 | 0.173 |
| Turbine Efficiency (%-meas T) | 165.8 | 98.8 | 111.2 | -5.1 | 69.0 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 168.5 | 157.8 | 311.5 | 161.6 | 123.1 |
| U/V' | 0.762 | 0.755 | 0.795 | 0.790 | 0.783 |
| Load Coef | 1.426 | 0.867 | 0.879 | -0.041 | 0.562 |
| Inlet Temp (R) | 968.3 | 1181.7 | 735.2 | 763.2 | 850.4 |
| Discharge Temp (R) | 937.0 | 1151.6 | 728.9 | 763.9 | 833.5 |
| Inlet Press (psia) | 15.456 | 15.834 | 14.826 | 15.342 | 15.927 |
| Discharge Press (psia) | 14.395 | 14.376 | 14.427 | 14.381 | 14.350 |
| | | | | | |
| Compressor Power (HP) | 0.58 | 1.04 | 0.15 | 0.44 | 0.92 |
| Eff-comprXEff-turb | 0.400 | 0.517 | -0.076 | 0.323 | 0.320 |
| Eff-turb from Eff-compr w/o HT | 77.34 | 80.82 | 102.79 | 83.08 | 74.24 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

| Rdg#/Hr:Mn | 11/15:07 | 12/15:18 | 13/15:29 | 14/15:41 | 15/15:49 |
|---|---|---|---|---|---|
| Engine Speed (RPM) | 2007 | 2004 | 2498 | 2499 | 2505 |
| Torque (ft-#) | 53.2 | 104.4 | 2.4 | 48.8 | 143.7 |
| Horsepower (HP) | 20.3 | 39.8 | 1.1 | 23.2 | 68.5 |
| sfc (#/HP-hr) | 0.544 | 0.427 | 8.074 | 0.640 | 0.425 |
| Air/Fuel Ratio | 49.11 | 33.62 | 70.11 | 46.28 | 28.17 |
| Dry Air/Fuel Ratio | 48.14 | 32.91 | 68.62 | 45.29 | 27.58 |
| Rel Humidity (%) | 47 | 47 | 47 | 47 | 47 |
| Dry Bulb Temp (R) | 561.3 | 563.4 | 563.4 | 563.7 | 563.2 |
| Engine delta P (psi) | -0.44 | 0.33 | -0.97 | -0.34 | 1.79 |
| Air Rate (#/hr) | 543.3 | [illegible] | 646.1 | 687.9 | 820.6 |
| Fuel Rate (#/hr) | 11.063 | 17.004 | 9.216 | 14.865 | 29.131 |
| Fuel time (sec) | 325.4 | 211.7 | 195.1 | 242.2 | 123.6 |
| Fuel Temp (R) | 575.8 | 573.2 | 577.9 | 577.1 | 574.4 |
| Crank Case Oil Temp (R) | 679.1 | 684.4 | 686.7 | 691.3 | 701.6 |
| | | | | | |
| Compressor Pressure Ratio | 1.113 | 1.216 | 1.124 | 1.220 | 1.556 |
| Corrected Flow (CFM) | 126.9 | 133.8 | 151.7 | 161.7 | 193.9 |
| Corrected Flow (#/sec) | 0.162 | 0.171 | 0.193 | 0.206 | 0.247 |
| Compressor Efficiency (%) | 44.0 | 52.9 | 45.2 | 54.2 | 62.4 |
| Compr Eff w/o .0008HT(%) | 58.3 | 66.9 | 54.1 | 63.7 | 69.0 |
| Inlet Temp (R) | 562.9 | 564.2 | 564.8 | 565.2 | 565.3 |
| Discharge Temp (R) | 602.6 | 625.7 | 607.3 | 626.2 | 687.3 |
| Inlet Press (psia) | 14.287 | 14.274 | 14.237 | 14.221 | 14.155 |
| Discharge Press (psia) | 15.899 | 17.363 | 16.003 | 17.349 | 22.023 |
| Corrected Speed (RPM/√O) | 43849 | 53905 | 48529 | 57622 | 79821 |
| Actual Speed (RPM) | 45680 | 56220 | 50640 | 60150 | 83330 |
| | | | | | |
| Turbine Expansion Ratio | 1.142 | 1.195 | 1.190 | 1.244 | 1.444 |
| Corrected Speed (rpm) | 32195 | 36345 | 36729 | 40452 | 49270 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.290 | 0.290 | 0.290 | 0.290 | 0.290 |
| Corrected Flow (#/sec) | 0.197 | 0.218 | 0.217 | 0.241 | 0.290 |
| Turbine Efficiency (%-meas T) | 77.0 | 71.5 | 68.3 | 56.4 | -217.4 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 120.0 | 112.7 | 103.4 | 98.8 | 87.8 |
| U/V' | 0.759 | 0.741 | 0.758 | 0.746 | 0.708 |
| Load Coef | 0.668 | 0.651 | 0.594 | 0.507 | -2.169 |
| Inlet Temp (R) | 1044.2 | 1241.1 | 986.0 | 1146.8 | 1483.7 |
| Discharge Temp (R) | 1015.5 | 1199.7 | 954.4 | 1109.5 | 1772.8 |
| Inlet Press (psia) | 16.338 | 17.032 | 16.970 | 17.684 | 20.232 |
| Discharge Press (psia) | 14.312 | 14.257 | 14.263 | 14.211 | 14.01[illegible] |
| | | | | | |
| Compressor Power (HP) | 1.54 | 2.63 | 2.16 | 3.38 | 8.57 |
| Eff-comprXEff-turb | 0.442 | 0.513 | 0.396 | 0.465 | 0.496 |
| Eff-turb from Eff-compr w/o HT | 75.69 | 76.70 | 73.14 | 73.06 | 71.87 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.42

| Rdg#/Hr:Mn | 16/15:58 | 17/16:07 | 18/16:14 |
|---|---|---|---|
| Engine Speed (RPM) | 2504 | 2504 | 2003 |
| Torque (ft-#) | 194.4 | 204.9 | 229.9 |
| Horsepower (HP) | 92.7 | 97.7 | 87.7 |
| sfc (#/HP-hr) | 0.400 | 0.400 | 0.385 |
| Air/Fuel Ratio | 24.17 | 23.33 | 20.12 |
| Dry Air/Fuel Ratio | 23.64 | 22.77 | 19.64 |
| Rel Humidity (%) | 47 | 47 | 47 |
| Dry Bulb Temp (R) | 564.5 | 567.4 | 567.4 |
| Engine delta P (psi) | 3.04 | 3.32 | 3.27 |
| Air Rate (#/hr) | 895.2 | 912.8 | 679.9 |
| Fuel Rate (#/hr) | 37.033 | 39.118 | 33.784 |
| Fuel time (sec) | 97.2 | 92.0 | 106.6 |
| Fuel Temp (R) | 574.8 | 569.8 | 581.3 |
| Crank Case Oil Temp (R) | 711.5 | 710.0 | 712.4 |
| | | | |
| Compressor Pressure Ratio | 1.762 | 1.809 | 1.590 |
| Corrected Flow (CFM) | 212.6 | 217.2 | 160.6 |
| Corrected Flow (#/sec) | 0.271 | 0.277 | 0.205 |
| Compressor Efficiency (%) | 63.2 | 64.3 | 59.5 |
| Compr Eff w/o .0008HT(%) | 68.4 | 69.4 | 68.5 |
| Inlet Temp (R) | 566.9 | 568.3 | 570.7 |
| Discharge Temp (R) | 724.7 | 731.6 | 706.7 |
| Inlet Press (psia) | 14.102 | 14.088 | 14.221 |
| Discharge Press (psia) | 24.845 | 25.480 | 22.617 |
| Corrected Speed (RPM/√O) | 89618 | 91829 | 78298 |
| Actual Speed (RPM) | 93690 | 96120 | 82130 |
| | | | |
| Turbine Expansion Ratio | 1.571 | 1.600 | 1.376 |
| Corrected Speed (rpm) | 52806 | 53733 | 45146 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.290 | 0.290 | 0.290 |
| Corrected Flow (#/sec) | 0.310 | 0.314 | 0.274 |
| Turbine Efficiency (%-meas T) | 64.3 | 66.8 | 68.2 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 83.2 | 81.4 | 96.0 |
| U/V' | 0.687 | 0.687 | 0.693 |
| Load Coef | 0.680 | 0.708 | 0.709 |
| Inlet Temp (R) | 1632.8 | 1659.8 | 1716.6 |
| Discharge Temp (R) | 1517.6 | 1533.8 | 1625.3 |
| Inlet Press (psia) | 21.809 | 22.163 | 19.351 |
| Discharge Press (psia) | 13.880 | 13.849 | 14.059 |
| | | | |
| Compressor Power (HP) | 12.35 | 13.06 | 7.61 |
| Eff-comprXEff-turb | 0.482 | 0.480 | 0.514 |
| Eff-turb from Eff-compr w/o HT | 70.41 | 69.13 | 75.06 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.269 |

"S/N69, 2.66I/D, Army#1 on Deere 4239T"

barometer is 29.48

| Rdg#/Hr:Mn | 24/08:41 | 25/08:54 | 26/09:09 | 27/09:30 | 28/09:57 |
|---|---|---|---|---|---|
| Engine Speed (RPM) | 1510 | 1507 | 1507 | 1505 | 2000 |
| Torque (ft-#) | 162.3 | 108.0 | 54.0 | 0.8 | 1.2 |
| Horsepower (HP) | 46.7 | 31.0 | 15.5 | 0.2 | 0.5 |
| sfc (#/HP-hr) | 0.378 | 0.407 | 0.504 | 15.983 | 12.765 |
| Air/Fuel Ratio | 26.21 | 34.71 | 53.22 | 110.62 | 93.85 |
| Dry Air/Fuel Ratio | 25.82 | 34.18 | 52.39 | 108.85 | 92.29 |
| Rel Humidity (%) | 48 | 48 | 48 | 48 | 48 |
| Dry Bulb Temp (R) | 551.9 | 552.6 | 553.7 | 554.2 | 555.2 |
| Engine delta P (psi) | 1.18 | 0.34 | -0.29 | -0.56 | -0.90 |
| Air Rate (#/hr) | 462.5 | 437.3 | 415.3 | 405.3 | 547.4 |
| Fuel Rate (#/hr) | 17.644 | 12.600 | 7.803 | 3.664 | 5.833 |
| Fuel time (sec) | 204.0 | 285.7 | 461.4 | 490.9 | 308.3 |
| Fuel Temp (R) | 564.3 | 568.4 | 575.2 | 573.6 | 568.1 |
| Crank Case Oil Temp (R) | 681.1 | 678.2 | 670.7 | 662.9 | 671.2 |
| | | | | | |
| Compressor Pressure Ratio | 1.275 | 1.173 | 1.090 | 1.056 | 1.103 |
| Corrected Flow (CFM) | 106.8 | 100.8 | 95.6 | 93.6 | 126.9 |
| Corrected Flow (#/sec) | 0.136 | 0.129 | 0.122 | 0.119 | 0.162 |
| Compressor Efficiency (%) | 53.3 | 49.2 | 42.5 | 41.7 | 48.3 |
| Compr Eff w/o .0008HT(%) | 71.0 | 69.3 | 63.5 | 56.9 | 58.3 |
| Inlet Temp (R) | 554.1 | 554.7 | 555.1 | 555.3 | 555.8 |
| Discharge Temp (R) | 629.0 | 607.4 | 587.7 | 576.2 | 588.5 |
| Inlet Press (psia) | 14.338 | 14.365 | 14.390 | 14.350 | 14.305 |
| Discharge Press (psia) | 18.283 | 16.853 | 15.684 | 15.154 | 15.778 |
| Corrected Speed (RPM/√O) | 55507 | 46570 | 37187 | 32193 | 42979 |
| Actual Speed (RPM) | 57370 | 48160 | 38470 | 33310 | 44490 |
| | | | | | |
| Turbine Expansion Ratio | 1.195 | 1.151 | 1.111 | 1.092 | 1.166 |
| Corrected Speed (rpm) | 35538 | 32124 | 28245 | 27439 | 34865 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.235 | 0.235 | 0.235 | 0.235 | 0.235 |
| Corrected Flow (#/sec) | 0.185 | 0.167 | 0.147 | 0.129 | 0.173 |
| Turbine Efficiency (%-meas T) | 93.9 | 106.8 | 132.4 | 32.6 | 66.1 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 125.4 | 133.7 | 139.6 | 145.2 | 110.0 |
| U/V' | 0.723 | 0.736 | 0.745 | 0.794 | 0.767 |
| Load Coef | 0.897 | 0.987 | 1.191 | 0.258 | 0.563 |
| Inlet Temp (R) | 1351.7 | 1165.8 | 962.2 | 764.4 | 844.6 |
| Discharge Temp (R) | 1293.0 | 1119.3 | 925.5 | 758.[illegible] | 821.1 |
| Inlet Press (psia) | 17.107 | 16.51[illegible] | 15.970 | 15.718 | 16.678 |
| Discharge Press (psia) | 14.312 | 14.349 | 14.372 | 14.398 | 14.309 |
| | | | | | |
| Compressor Power (HP) | 2.45 | 1.54 | 0.85 | 0.59 | 1.40 |
| Eff-comprXEff-turb | 0.572 | 0.550 | 0.476 | 0.457 | 0.432 |
| Eff-turb from Eff-compr w/o HT | 80.53 | 79.29 | 74.89 | 80.30 | 74.00 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

| | | | | | |
|---|---|---|---|---|---|
| Rdg#/Hr:Mn | 19/06:59 | 20/07:34 | 21/07:50 | 22/08:05 | 23/08:29 |
| Engine Speed (RPM) | 1325 | 1000 | 1007 | 1002 | 1008 |
| Torque (ft-#) | 1.1 | 0.5 | 49.3 | 98.9 | 148.1 |
| Horsepower (HP) | 0.3 | 0.1 | 9.5 | 18.9 | 28.4 |
| sfc (#/HP-hr) | 2.126 | 23.413 | 0.512 | 0.416 | 0.395 |
| Air/Fuel Ratio | 625.76 | 121.94 | 55.91 | 33.54 | 24.94 |
| Dry Air/Fuel Ratio | 618.20 | 120.38 | 55.16 | 33.10 | 24.58 |
| Rel Humidity (%) | 48 | 48 | 48 | 48 | 48 |
| Dry Bulb Temp (R) | 545.5 | 547.2 | 548.7 | 548.1 | 550.6 |
| Engine delta P (psi) | -0.54 | -0.46 | -0.33 | -0.17 | 0.24 |
| Air Rate (#/hr) | 369.2 | 271.8 | 270.4 | 263.3 | 280.1 |
| Fuel Rate (#/hr) | 0.590 | 2.229 | 4.836 | 7.850 | 11.232 |
| Fuel time (sec) | 61.0 | 806.6 | 371.9 | 229.1 | 320.5 |
| Fuel Temp (R) | 552.3 | 563.9 | 566.3 | 562.2 | 563.8 |
| Crank Case Oil Temp (R) | 613.6 | 650.5 | 656.2 | 661.6 | 670.3 |
| | | | | | |
| Compressor Pressure Ratio | 1.038 | 1.009 | 1.028 | 1.063 | 1.130 |
| Corrected Flow (CFM) | 84.4 | 62.2 | 62.0 | 60.3 | 64.6 |
| Corrected Flow (#/sec) | 0.108 | 0.079 | 0.079 | 0.077 | 0.082 |
| Compressor Efficiency (%) | 33.8 | 10.9 | 19.3 | 25.7 | 32.7 |
| Compr Eff w/o .0008HT(%) | 49.7 | 22.2 | 49.2 | 60.7 | 60.9 |
| Inlet Temp (R) | 547.2 | 549.0 | 550.3 | 550.8 | 553.6 |
| Discharge Temp (R) | 564.6 | 562.5 | 573.2 | 588.4 | 614.0 |
| Inlet Press (psia) | 14.394 | 14.395 | 14.399 | 14.408 | 14.354 |
| Discharge Press (psia) | 14.943 | 14.530 | 14.807 | 15.312 | 16.227 |
| Corrected Speed (RPM/√O) | 28186 | 20869 | 25621 | 32499 | 42038 |
| Actual Speed (RPM) | 28950 | 21470 | 26390 | 33490 | 43430 |
| | | | | | |
| Turbine Expansion Ratio | 1.075 | 1.040 | 1.050 | 1.075 | 1.110 |
| Corrected Speed (rpm) | 24313 | 18238 | 20180 | 23377 | 27783 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.235 | 0.235 | 0.235 | 0.235 | 0.235 |
| Corrected Flow (#/sec) | 0.116 | 0.088 | 0.097 | 0.102 | 0.116 |
| Turbine Efficiency (%-meas T) | 43.7 | 132.2 | 249.9 | 182.9 | 136.1 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 157.2 | 238.9 | 243.7 | 214.2 | 192.1 |
| U/V' | 0.776 | 0.788 | 0.782 | 0.743 | 0.736 |
| Load Coef | 0.363 | 1.063 | 2.045 | 1.657 | 1.255 |
| Inlet Temp (R) | 735.4 | 718.8 | 887.0 | 1064.5 | 1267.4 |
| Discharge Temp (R) | 728.9 | 708.3 | 857.1 | 1026.3 | 1219.9 |
| Inlet Press (psia) | 15.480 | 14.995 | 15.138 | 15.480 | 15.990 |
| Discharge Press (psia) | 14.403 | 14.420 | 14.420 | 14.401 | 14.408 |
| | | | | | |
| Compressor Power (HP) | 0.41 | 0.17 | 0.23 | 0.40 | 0.86 |
| Eff-comprXEff-turb | 0.392 | 0.182 | 0.355 | 0.432 | 0.512 |
| Eff-turb from Eff-compr w/o HT | 78.88 | 82.03 | 72.17 | 71.11 | 93.98 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.48

| | | | | | |
|---|---|---|---|---|---|
| Rdg#/Hr:Mn | 29/10:26 | 30/10:44 | 31/10:51 | 32/11:01 | 33/11:12 |
| Engine Speed (RPM) | 2001 | 2001 | 2007 | 2006 | 2503 |
| Torque (ft-#) | 52.3 | 104.1 | 155.3 | 208.6 | 0.6 |
| Horsepower (HP) | 19.9 | 39.7 | 59.3 | 79.7 | 0.3 |
| sfc (#/HP-hr) | 0.562 | 0.432 | 0.387 | 0.377 | 31.446 |
| Air/Fuel Ratio | 51.51 | 36.47 | 29.41 | 24.25 | 77.36 |
| Dry Air/Fuel Ratio | 50.60 | 35.79 | 28.85 | 23.76 | 75.84 |
| Rel Humidity (%) | 48 | 48 | 48 | 48 | 48 |
| Dry Bulb Temp (R) | 557.1 | 559.1 | 559.8 | 561.1 | 560.4 |
| Engine delta P (psi) | -0.27 | 0.69 | 1.71 | 3.14 | -0.95 |
| Air Rate (#/hr) | 576.4 | 625.0 | 675.6 | 727.7 | 695.6 |
| Fuel Rate (#/hr) | 11.190 | 17.136 | 22.972 | 30.008 | 8.992 |
| Fuel time (sec) | 321.7 | 210.1 | 156.7 | 120.0 | 200.0 |
| Fuel Temp (R) | 571.4 | 573.5 | 571.6 | 570.9 | 576.4 |
| Crank Case Oil Temp (R) | 678.9 | 685.7 | 691.3 | 699.7 | 690.3 |
| | | | | | |
| Compressor Pressure Ratio | 1.194 | 1.340 | 1.492 | 1.699 | 1.220 |
| Corrected Flow (CFM) | 134.0 | 145.8 | 158.0 | 170.9 | 163.0 |
| Corrected Flow (#/sec) | 0.171 | 0.186 | 0.201 | 0.218 | 0.208 |
| Compressor Efficiency (%) | 55.7 | 60.7 | 63.0 | 63.2 | 56.9 |
| Compr Eff w/o .0008HT(%) | 67.0 | 70.4 | 71.1 | 69.7 | 63.7 |
| Inlet Temp (R) | 557.9 | 560.0 | 561.0 | 562.8 | 562.4 |
| Discharge Temp (R) | 610.0 | 640.5 | 668.9 | 708.6 | 620.1 |
| Inlet Press (psia) | 14.294 | 14.268 | 14.242 | 14.206 | 14.230 |
| Discharge Press (psia) | 17.067 | 19.119 | 21.245 | 24.140 | 17.354 |
| Corrected Speed (RPM/√O) | 52212 | 63615 | 73049 | 83761 | 57448 |
| Actual Speed (RPM) | 54150 | 66100 | 75970 | 87250 | 59820 |
| | | | | | |
| Turbine Expansion Ratio | 1.214 | 1.296 | 1.380 | 1.492 | 1.288 |
| Corrected Speed (rpm) | 38378 | 43160 | 46891 | 50781 | 43609 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.235 | 0.235 | 0.235 | 0.235 | 0.235 |
| Corrected Flow (#/sec) | 0.195 | 0.218 | 0.236 | 0.253 | 0.216 |
| Turbine Efficiency (%-meas T) | 81.8 | 78.2 | 80.5 | 81.5 | 65.6 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 108.3 | 103.1 | 97.7 | 93.3 | 96.9 |
| U/V' | 0.751 | 0.733 | 0.717 | 0.700 | 0.751 |
| Load Coef | 0.725 | 0.727 | 0.783 | 0.831 | 0.582 |
| Inlet Temp (R) | 1032.6 | 1216.6 | 1361.5 | 1531.2 | 976.0 |
| Discharge Temp (R) | 988.7 | 1152.4 | 1271.6 | 1407.5 | 932.7 |
| Inlet Press (psia) | 17.337 | 18.425 | 19.537 | 20.999 | 18.308 |
| Discharge Press (psia) | 14.282 | 14.221 | 14.159 | 14.073 | 14.219 |
| | | | | | |
| Compressor Power (HP) | 2.36 | 4.10 | 6.11 | 9.11 | 3.39 |
| Eff-comprXEff-turb | 0.511 | 0.547 | 0.548 | 0.533 | 0.476 |
| Eff-turb from Eff-compr w/o HT | 76.25 | 77.73 | 77.07 | 76.50 | 74.66 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

| Rdg#/Hr:Mn | 34/11:24 | 35/11:34 | 36/11:45 | 37/11:52 | 38/12:03 |
|---|---|---|---|---|---|
| Engine Speed (RPM) | 2502 | 2503 | 2504 | 2503 | 2000 |
| Torque (ft-#) | 49.0 | 97.9 | 144.7 | 195.0 | 239.6 |
| Horsepower (HP) | 23.3 | 46.7 | 69.0 | 92.9 | 91.2 |
| sfc (#/HP-hr) | 0.655 | 0.479 | 0.426 | 0.400 | 0.375 |
| Air/Fuel Ratio | 49.58 | 38.68 | 31.92 | 27.43 | 22.29 |
| Dry Air/Fuel Ratio | 48.87 | 38.11 | 31.42 | 26.99 | 21.93 |
| Rel Humidity (%) | 36 | 36 | 36 | 36 | 36 |
| Dry Bulb Temp (R) | 559.9 | 560.5 | 562.5 | 563.2 | 563.3 |
| Engine delta P (psi) | -0.09 | 1.11 | 2.28 | 3.59 | 4.01 |
| Air Rate (#/hr) | 757.6 | 863.9 | 938.7 | 1019.8 | 763.6 |
| Fuel Rate (#/hr) | 15.279 | 22.334 | 29.405 | 37.175 | 34.256 |
| Fuel time (sec) | 235.6 | 161.2 | 122.4 | 96.8 | 105.1 |
| Fuel Temp (R) | 577.2 | 576.5 | 570.4 | 568.3 | 570.2 |
| Crank Case Oil Temp (R) | 690.7 | 695.8 | 702.8 | 707.8 | 699.3 |
| | | | | | |
| Compressor Pressure Ratio | 1.369 | 1.608 | 1.836 | 2.098 | 1.509 |
| Corrected Flow (CFM) | 177.9 | 203.6 | 222.3 | 242.6 | 148.5 |
| Corrected Flow (#/sec) | 0.227 | 0.259 | 0.283 | 0.309 | 0.189 |
| Compressor Efficiency (%) | 62.5 | 65.3 | 65.8 | 65.5 | 42.6 |
| Compr Eff w/o .0008HT(%) | 68.9 | 70.1 | 69.6 | 68.5 | 46.5 |
| Inlet Temp (R) | 561.6 | 562.2 | 563.6 | 564.8 | 564.8 |
| Discharge Temp (R) | 645.9 | 687.4 | 726.2 | 768.5 | 730.5 |
| Inlet Press (psia) | 14.195 | 14.150 | 14.099 | 14.048 | 17.190 |
| Discharge Press (psia) | 19.427 | 22.754 | 25.892 | 29.478 | 25.944 |
| Corrected Speed (RPM/√O) | 68839 | 82557 | 93151 | 103517 | 89813 |
| Actual Speed (RPM) | 71630 | 85950 | 97100 | 108020 | 93720 |
| | | | | | |
| Turbine Expansion Ratio | 1.381 | 1.546 | 1.699 | 1.881 | 1.566 |
| Corrected Speed (rpm) | 48433 | 54341 | 58609 | 62507 | 53047 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.235 | 0.235 | 0.235 | 0.235 | 0.235 |
| Corrected Flow (#/sec) | 0.239 | 0.264 | 0.277 | 0.288 | 0.262 |
| Turbine Efficiency (%-meas T) | 71.4 | 71.1 | 73.7 | 74.2 | 84.7 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 93.1 | 88.3 | 85.4 | 82.3 | 89.3 |
| U/V' | 0.740 | 0.720 | 0.708 | 0.696 | 0.693 |
| Load Coef | 0.651 | 0.685 | 0.735 | 0.765 | 0.881 |
| Inlet Temp (R) | 1134.5 | 1297.6 | 1423.7 | 1549.0 | 1619.0 |
| Discharge Temp (R) | 1066.3 | 1196.1 | 1286.5 | 1374.3 | 1469.0 |
| Inlet Press (psia) | 19.520 | 21.647 | 23.614 | 25.884 | 21.931 |
| Discharge Press (psia) | 14.131 | 14.005 | 13.902 | 13.760 | 14.006 |
| | | | | | |
| Compressor Power (HP) | 5.48 | 9.54 | 13.66 | 18.80 | 10.97 |
| Eff-comprXEff-turb | 0.515 | 0.523 | 0.516 | 0.499 | 0.345 |
| Eff-turb from Eff-compr w/o HT | 74.77 | 74.59 | 74.07 | 72.82 | 74.30 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.44

| Rdg#/Hr:Mn | 39/12:11 | 40/12:40 | 41/12:53 | 42/13:07 | 43/13:19 |
|---|---|---|---|---|---|
| Engine Speed (RPM) | 2503 | 1013 | 1006 | 1002 | 1508 |
| Torque (ft-#) | 207.3 | 98.8 | 148.4 | 196.7 | 107.8 |
| Horsepower (HP) | 98.8 | 19.1 | 28.4 | 37.5 | 31.0 |
| sfc (#/HP-hr) | 0.397 | 0.416 | 0.401 | 0.416 | 0.409 |
| Air/Fuel Ratio | 26.62 | 36.45 | 25.29 | 19.32 | 36.45 |
| Dry Air/Fuel Ratio | 26.23 | 35.95 | 24.93 | 19.06 | 35.93 |
| Rel Humidity (%) | 32 | 32 | 32 | 32 | 32 |
| Dry Bulb Temp (R) | 563.6 | 562.0 | 562.8 | 562.3 | 563.3 |
| Engine delta P (psi) | 3.90 | -0.23 | 0.20 | 1.15 | 0.24 |
| Air Rate (#/hr) | 1043.5 | 289.1 | 288.3 | 301.5 | 461.3 |
| Fuel Rate (#/hr) | 39.207 | 7.931 | 11.401 | 15.603 | 12.657 |
| Fuel time (sec) | 91.8 | 226.8 | 315.8 | 230.7 | 284.4 |
| Fuel Temp (R) | 568.7 | 571.5 | 575.9 | 571.7 | 576.6 |
| Crank Case Oil Temp (R) | 708.5 | 669.5 | 673.5 | 681.7 | 678.5 |
| | | | | | |
| Compressor Pressure Ratio | 2.173 | 1.089 | 1.164 | 1.279 | 1.271 |
| Corrected Flow (CFM) | 248.7 | 67.1 | 67.1 | 70.2 | 107.8 |
| Corrected Flow (#/sec) | 0.317 | 0.085 | 0.086 | 0.090 | 0.137 |
| Compressor Efficiency (%) | 65.3 | 32.7 | 38.0 | 41.6 | 57.0 |
| Compr Eff w/o .0008HT(%) | 68.2 | 60.7 | 63.9 | 62.6 | 70.8 |
| Inlet Temp (R) | 565.7 | 565.2 | 566.0 | 566.8 | 566.4 |
| Discharge Temp (R) | 781.1 | 607.9 | 632.1 | 666.1 | 636.9 |
| Inlet Press (psia) | 14.036 | 14.414 | 14.373 | 14.371 | 14.330 |
| Discharge Press (psia) | 30.502 | 15.698 | 16.727 | 18.380 | 18.210 |
| Corrected Speed (RPM/√Θ) | 105943 | 36269 | 45711 | 56890 | 55178 |
| Actual Speed (RPM) | 110640 | 37860 | 47750 | 59470 | 57660 |
| | | | | | |
| Turbine Expansion Ratio | 1.938 | 1.107 | 1.151 | 1.202 | 1.258 |
| Corrected Speed (rpm) | 63310 | 26205 | 30412 | 34913 | 38444 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.235 | 0.177 | 0.177 | 0.177 | 0.177 |
| Corrected Flow (#/sec) | 0.290 | 0.110 | 0.116 | 0.128 | 0.161 |
| Turbine Efficiency (%-meas T) | 73.7 | 152.4 | 125.1 | 115.5 | 100.9 |
| Turbine Efficiency (%-cmpr+brq Pwr) | 81.3 | 168.8 | 156.1 | 147.6 | 109.4 |
| U/V' | 0.690 | 0.703 | 0.696 | 0.700 | 0.693 |
| Load Coef | 0.773 | 1.544 | 1.290 | 1.178 | 1.051 |
| Inlet Temp (R) | 1584.1 | 1082.7 | 1278.7 | 1505.0 | 1166.8 |
| Discharge Temp (R) | 1399.6 | 1037.3 | 1219.7 | 1423.5 | 1095.7 |
| Inlet Press (psia) | 26.598 | 15.929 | 16.528 | 17.233 | 17.975 |
| Discharge Press (psia) | 13.722 | 14.385 | 14.364 | 14.336 | 14.290 |
| | | | | | |
| Compressor Power (HP) | 20.40 | 0.63 | 1.07 | 1.88 | 2.47 |
| Eff-comprXEff-turb | 0.493 | 0.437 | 0.480 | 0.510 | 0.527 |
| Eff-turb from Eff-compr w/o HT | 72.24 | 72.11 | 75.12 | 81.41 | 74.48 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.269 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.42

| | | |
|---|---|---|
| Rdg#/Hr:Mn | 44/13:35 | 45/13:47 |
| Engine Speed (RPM) | 1501 | 1512 |
| Torque (ft-#) | 162.0 | 216.3 |
| Horsepower (HP) | 46.3 | 62.3 |
| sfc (#/HP-hr) | 0.383 | 0.379 |
| Air/Fuel Ratio | 27.81 | 23.13 |
| Dry Air/Fuel Ratio | 27.48 | 22.86 |
| Rel Humidity (%) | 26 | 26 |
| Dry Bulb Temp (R) | 563.8 | 563.5 |
| Engine delta P (psi) | 1.25 | 2.73 |
| Air Rate (#/hr) | 493.7 | 545.9 |
| Fuel Rate (#/hr) | 17.755 | 23.600 |
| Fuel time (sec) | 202.8 | 152.5 |
| Fuel Temp (R) | 572.1 | 570.2 |
| Crank Case Oil Temp (R) | 682.8 | 689.6 |
| | | |
| Compressor Pressure Ratio | 1.410 | 1.622 |
| Corrected Flow (CFM) | 115.7 | 128.0 |
| Corrected Flow (#/sec) | 0.147 | 0.163 |
| Compressor Efficiency (%) | 59.3 | 59.5 |
| Compr Eff w/o .0008HT(%) | 70.9 | 68.2 |
| Inlet Temp (R) | 566.4 | 566.7 |
| Discharge Temp (R) | 665.1 | 708.1 |
| Inlet Press (psia) | 14.286 | 14.280 |
| Discharge Press (psia) | 20.145 | 23.164 |
| Corrected Speed (RPM/√O) | 65350 | 78115 |
| Actual Speed (RPM) | 68290 | 81650 |
| | | |
| Turbine Expansion Ratio | 1.327 | 1.440 |
| Corrected Speed (rpm) | 42611 | 47438 |
| % Des Corr Speed (%) | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.177 | 0.177 |
| Corrected Flow (#/sec) | 0.177 | 0.196 |
| Turbine Efficiency (%-meas T) | 93.4 | 92.8 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 106.2 | 100.5 |
| U/V' | 0.693 | 0.684 |
| Load Coef | 0.972 | 0.993 |
| Inlet Temp (R) | 1332.2 | 1536.6 |
| Discharge Temp (R) | 1241.7 | 1407.3 |
| Inlet Press (psia) | 18.896 | 20.430 |
| Discharge Press (psia) | 14.234 | 14.187 |
| | | |
| Compressor Power (HP) | 3.85 | 6.37 |
| Eff-comprXEff-turb | 0.544 | 0.528 |
| Eff-turb from Eff-compr w/o HT | 76.74 | 77.46 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

| Rdg#/Hr:Mn | 46/08:04 | 47/09:10 | 48/09:18 | 49/09:27 | 50/09:37 |
|---|---|---|---|---|---|
| Engine Speed (RPM) | 1478 | 1998 | 2006 | 2507 | 1512 |
| Torque (ft-#) | 21.5 | 156.5 | 208.7 | 97.1 | 247.1 |
| Horsepower (HP) | 6.1 | 59.5 | 79.7 | 46.3 | 71.1 |
| sfc (#/HP-hr) | -0.098 | 0.397 | 0.380 | 0.500 | 0.381 |
| Air/Fuel Ratio | -676.44 | 32.87 | 28.12 | 43.93 | 21.19 |
| Dry Air/Fuel Ratio | -667.35 | 32.36 | 27.65 | 43.19 | 20.83 |
| Rel Humidity (%) | 51 | 50 | 50 | 50 | 50 |
| Dry Bulb Temp (R) | 546.9 | 552.0 | 554.2 | 554.6 | 554.6 |
| Engine delta P (psi) | -0.75 | 1.79 | 3.21 | 0.35 | 3.71 |
| Air Rate (#/hr) | 399.1 | 777.2 | 850.9 | 1019.1 | 574.6 |
| Fuel Rate (#/hr) | -0.590 | 23.647 | 30.255 | 23.197 | 27.115 |
| Fuel time (sec) | 61.0 | 152.2 | 119.0 | 155.2 | 132.8 |
| Fuel Temp (R) | 549.3 | 559.3 | 563.9 | 567.6 | 564.8 |
| Crank Case Oil Temp (R) | 610.5 | 694.0 | 701.3 | 703.1 | 696.9 |
| | | | | | |
| Compressor Pressure Ratio | 1.108 | 1.800 | 2.086 | 2.057 | 1.770 |
| Corrected Flow (CFM) | 91.5 | 181.2 | 199.4 | 240.6 | 133.8 |
| Corrected Flow (#/sec) | 0.117 | 0.231 | 0.254 | 0.307 | 0.171 |
| Compressor Efficiency (%) | 52.3 | 65.4 | 64.7 | 66.3 | 61.3 |
| Compr Eff w/o .0008HT(%) | 69.4 | 69.6 | 68.0 | 68.5 | 69.3 |
| Inlet Temp (R) | 547.6 | 553.2 | 555.1 | 555.8 | 556.9 |
| Discharge Temp (R) | 578.9 | 708.1 | 755.9 | 747.8 | 718.1 |
| Inlet Press (psia) | 14.357 | 14.191 | 14.143 | 14.043 | 14.253 |
| Discharge Press (psia) | 15.914 | 25.549 | 29.502 | 28.883 | 25.230 |
| Corrected Speed (RPM/√O) | 39543 | 90353 | 100154 | 102004 | 84937 |
| Actual Speed (RPM) | 40630 | 93310 | 103610 | 105590 | 88010 |
| | | | | | |
| Turbine Expansion Ratio | 1.161 | 1.694 | 1.888 | 2.071 | 1.519 |
| Corrected Speed (rpm) | 32005 | 58724 | 61975 | 67459 | 49976 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.177 | 0.177 | 0.177 | 0.177 | 0.177 |
| Corrected Flow (#/sec) | 0.124 | 0.219 | 0.229 | 0.233 | 0.201 |
| Turbine Efficiency (%-meas T) | 99.5 | 80.1 | 80.1 | 74.1 | 92.6 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 115.7 | 90.4 | 87.1 | 84.5 | 95.1 |
| U/V' | 0.713 | 0.712 | 0.688 | 0.705 | 0.675 |
| Load Coef | 0.980 | 0.790 | 0.845 | 0.745 | 1.017 |
| Inlet Temp (R) | 835.9 | 1309.6 | 1449.7 | 1270.8 | 1608.6 |
| Discharge Temp (R) | 801.7 | 1171.5 | 1270.1 | 1102.9 | 1455.8 |
| Inlet Press (psia) | 16.660 | 23.762 | 26.296 | 28.530 | 21.521 |
| Discharge Press (psia) | 14.349 | 14.031 | 13.925 | 13.776 | 14.167 |
| | | | | | |
| Compressor Power (HP) | 0.89 | 10.71 | 15.40 | 17.94 | 7.76 |
| Eff-comprXEff-turb | 0.469 | 0.534 | 0.517 | 0.517 | 0.519 |
| Eff-turb from Eff-compr w/o HT | 67.50 | 76.76 | 76.04 | 75.42 | 74.93 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

| Rdg#/Hr:Mn | 51/09:56 | 52/10:12 | 53/10:21 | 54/10:33 | 55/10:45 |
|---|---|---|---|---|---|
| Engine Speed (RPM) | 1503 | 1008 | 2003 | 2498 | 1010 |
| Torque (ft-#) | 54.4 | 49.3 | 244.1 | 1.0 | 197.1 |
| Horsepower (HP) | 15.6 | 9.5 | 93.1 | 0.5 | 37.9 |
| sfc (#/HP-hr) | 0.518 | 0.523 | 0.375 | 23.062 | 0.407 |
| Air/Fuel Ratio | 53.79 | 55.24 | 25.90 | 83.43 | 21.23 |
| Dry Air/Fuel Ratio | 52.86 | 54.29 | 25.43 | 81.92 | 20.85 |
| Rel Humidity (%) | 50 | 50 | 50 | 50 | 50 |
| Dry Bulb Temp (R) | 555.3 | 555.1 | 556.4 | 556.6 | 556.6 |
| Engine delta P (psi) | -0.46 | -0.42 | 4.26 | -4.83 | 0.28 |
| Air Rate (#/hr) | 434.2 | 273.6 | 903.5 | 915.1 | 327.6 |
| Fuel Rate (#/hr) | 8.072 | 4.953 | 34.890 | 10.969 | 15.432 |
| Fuel time (sec) | 446.0 | 363.1 | 103.2 | 164.0 | 233.3 |
| Fuel Temp (R) | 574.4 | 573.8 | 564.9 | 570.1 | 575.7 |
| Crank Case Oil Temp (R) | 674.7 | 664.8 | 685.6 | 688.2 | 684.9 |
| | | | | | |
| Compressor Pressure Ratio | 1.156 | 1.049 | 2.279 | 1.771 | 1.322 |
| Corrected Flow (CFM) | 100.5 | 63.1 | 212.4 | 215.4 | 75.4 |
| Corrected Flow (#/sec) | 0.128 | 0.080 | 0.271 | 0.275 | 0.096 |
| Compressor Efficiency (%) | 53.7 | 27.2 | 65.3 | 68.4 | 43.7 |
| Compr Eff w/o .0008HT(%) | 69.8 | 54.5 | 68.2 | 70.5 | 60.0 |
| Inlet Temp (R) | 557.0 | 557.3 | 556.9 | 557.5 | 559.3 |
| Discharge Temp (R) | 600.9 | 585.6 | 783.6 | 702.2 | 665.7 |
| Inlet Press (psia) | 14.347 | 14.404 | 14.119 | 14.108 | 14.451 |
| Discharge Press (psia) | 16.584 | 15.112 | 32.180 | 24.983 | 19.103 |
| Corrected Speed (RPM/√O) | 44650 | 29724 | 106671 | 95646 | 62210 |
| Actual Speed (RPM) | 46270 | 30810 | 110530 | 99160 | 64600 |
| | | | | | |
| Turbine Expansion Ratio | 1.189 | 1.078 | 2.014 | 2.147 | 1.316 |
| Corrected Speed (rpm) | 33870 | 23275 | 64425 | 70255 | 38528 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.177 | 0.177 | 0.177 | 0.111 | 0.111 |
| Corrected Flow (#/sec) | 0.145 | 0.097 | 0.235 | 0.179 | 0.125 |
| Turbine Efficiency (%-meas T) | 105.2 | 190.1 | 81.3 | 75.8 | 101.8 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 113.4 | 189.0 | 84.8 | 77.9 | 110.5 |
| U/V' | 0.702 | 0.725 | 0.685 | 0.720 | 0.630 |
| Load Coef | 1.068 | 1.810 | 0.867 | 0.731 | 1.250 |
| Inlet Temp (R) | 968.0 | 908.9 | 1526.7 | 1033.3 | 1458.0 |
| Discharge Temp (R) | 920.4 | 872.9 | 1318.5 | 884.0 | 1354.0 |
| Inlet Press (psia) | 17.039 | 15.527 | 27.919 | 29.815 | 18.820 |
| Discharge Press (psia) | 14.336 | 14.398 | 13.863 | 13.885 | 14.290 |
| | | | | | |
| Compressor Power (HP) | 1.38 | 0.36 | 18.57 | 12.15 | 2.40 |
| Eff-comprXEff-turb | 0.496 | 0.390 | 0.510 | 0.477 | 0.400 |
| Eff-turb from Eff-compr w/o HT | 71.02 | 71.59 | 74.81 | 67.71 | 67.00 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

| Rdg#/Hr:Mn | 56/10:56 | 57/11:08 | 58/12:38 | 59/13:51 | 60/14:00 |
|---|---|---|---|---|---|
| Engine Speed (RPM) | 1508 | 1495 | 875 | 852 | 990 |
| Torque (ft-#) | 216.0 | 250.6 | 0.5 | 0.8 | 0.4 |
| Horsepower (HP) | 62.0 | 71.3 | 0.1 | 0.1 | 0.3 |
| sfc (#/HP-hr) | 0.377 | 0.377 | 25.702 | 15.557 | 21.883 |
| Air/Fuel Ratio | 26.83 | 24.45 | 112.56 | 114.96 | 121.53 |
| Dry Air/Fuel Ratio | 26.31 | 24.00 | 111.07 | 113.46 | 119.91 |
| Rel Humidity (%) | 50 | 50 | 35 | 32 | 32 |
| Dry Bulb Temp (R) | 558.3 | 557.7 | 558.3 | 560.4 | 561.1 |
| Engine delta P (psi) | 1.57 | 2.60 | -2.12 | -1.89 | -2.94 |
| Air Rate (#/hr) | 626.4 | 658.3 | 241.0 | 232.1 | 302.6 |
| Fuel Rate (#/hr) | 23.351 | 26.920 | 2.141 | 2.019 | 2.490 |
| Fuel time (sec) | 154.2 | 133.7 | 839.9 | 890.8 | 722.2 |
| Fuel Temp (R) | 566.5 | 571.7 | [illegible] | 575.6 | 577.0 |
| Crank Case Oil Temp (R) | 687.5 | 690.5 | 653.1 | 650.0 | 652.6 |
| | | | | | |
| Compressor Pressure Ratio | 1.943 | 2.112 | 1.110 | 1.104 | 1.151 |
| Corrected Flow (CFM) | 145.9 | 153.4 | 55.7 | 53.8 | 70.2 |
| Corrected Flow (#/sec) | 0.186 | 0.195 | 0.071 | 0.069 | 0.089 |
| Compressor Efficiency (%) | 62.1 | 61.6 | 49.3 | 50.7 | 53.6 |
| Compr Eff w/o .0008HT(%) | 66.8 | 65.8 | 64.1 | 68.1 | 63.0 |
| Inlet Temp (R) | 559.8 | 559.8 | 560.8 | 562.3 | 562.3 |
| Discharge Temp (R) | 748.4 | 776.5 | 595.2 | 594.1 | 605.4 |
| Inlet Press (psia) | 14.285 | 14.282 | 14.423 | 14.382 | 14.386 |
| Discharge Press (psia) | 27.758 | 30.166 | 16.006 | 15.877 | 16.561 |
| Corrected Speed (RPM/√O) | 94833 | 99656 | 38325 | 36669 | 44286 |
| Actual Speed (RPM) | 98520 | 103530 | 39850 | 38180 | 46110 |
| | | | | | |
| Turbine Expansion Ratio | 1.858 | 1.962 | 1.259 | 1.233 | 1.355 |
| Corrected Speed (rpm) | 59077 | 60070 | 33032 | 31728 | 37896 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.111 | 0.111 | 0.043 | 0.043 | 0.043 |
| Corrected Flow (#/sec) | 0.169 | 0.175 | 0.066 | 0.065 | 0.078 |
| Turbine Efficiency (%-meas T) | 91.9 | 83.9 | 67.1 | 63.0 | 72.8 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 86.3 | 84.7 | 10[illegible].1 | 104.7 | 89.3 |
| U/V' | 0.664 | 0.650 | 0.596 | 0.600 | 0.599 |
| Load Coef | 0.928 | 0.994 | 0.944 | 0.877 | 1.016 |
| Inlet Temp (R) | 1442.5 | 1540.7 | 754.9 | 751.1 | 767.9 |
| Discharge Temp (R) | 1264.0 | 1331.6 | 722.9 | 723.8 | 721.8 |
| Inlet Press (psia) | 26.188 | 27.569 | 18.125 | 17.768 | 19.498 |
| Discharge Press (psia) | 14.095 | 14.055 | 14.398 | 14.410 | 14.390 |
| | | | | | |
| Compressor Power (HP) | 10.40 | 12.65 | 0.60 | 0.52 | 1.05 |
| Eff-comprXEff-turb | 0.479 | 0.472 | 0.349 | 0.366 | 0.358 |
| Eff-turb from Eff-compr w/o HT | 71.72 | 71.66 | 54.43 | 53.70 | 56.74 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.270 | 0.270 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.44

| Rdg#/Hr:Mn | 61/14:18 | 62/14:26 | 63/14:39 | 64/14:48 | 65/15:01 |
|---|---|---|---|---|---|
| Engine Speed (RPM) | 1495 | 1995 | 1002 | 747 | 1508 |
| Torque (ft-#) | 1.0 | 1.1 | 213.9 | 178.4 | 162.1 |
| Horsepower (HP) | 0.3 | 0.4 | 40.8 | 25.4 | 46.5 |
| sfc (#/HP-hr) | 17.902 | 22.071 | 0.482 | 0.582 | 0.392 |
| Air/Fuel Ratio | 101.18 | 86.94 | 15.78 | 13.15 | 23.54 |
| Dry Air/Fuel Ratio | 99.88 | 85.78 | 15.57 | 12.97 | 23.22 |
| Rel Humidity (%) | 31 | 31 | 31 | 31 | 31 |
| Dry Bulb Temp (R) | 561.0 | 562.3 | 562.0 | 562.4 | 562.5 |
| Engine delta P (psi) | -6.10 | -11.56 | -3.03 | -1.22 | 0.80 |
| Air Rate (#/hr) | 515.6 | 801.8 | 310.7 | 194.2 | 429.1 |
| Fuel Rate (#/hr) | 5.096 | 9.222 | 19.688 | 14.771 | 18.227 |
| Fuel time (sec) | 352.9 | 195.0 | 182.9 | 121.8 | 197.5 |
| Fuel Temp (R) | 576.0 | 574.8 | 572.3 | 571.7 | 570.6 |
| Crank Case Oil Temp (R) | 664.8 | 675.4 | 677.0 | 678.4 | 675.9 |
| | | | | | |
| Compressor Pressure Ratio | 1.456 | 1.912 | 1.493 | 1.241 | 1.188 |
| Corrected Flow (CFM) | 120.2 | 188.8 | 72.8 | 45.3 | 100.1 |
| Corrected Flow (#/sec) | 0.153 | 0.241 | 0.093 | 0.058 | 0.128 |
| Compressor Efficiency (%) | 68.8 | 67.4 | 43.5 | 31.3 | 46.6 |
| Compr Eff w/o .0008HT(%) | 72.7 | 69.2 | 57.0 | 57.8 | 71.8 |
| Inlet Temp (R) | 562.5 | 562.7 | 572.4 | 569.7 | 565.2 |
| Discharge Temp (R) | 655.3 | 732.7 | 732.3 | 685.3 | 626.4 |
| Inlet Press (psia) | 14.310 | 14.167 | 14.368 | 14.382 | 14.327 |
| Discharge Press (psia) | 20.836 | 27.094 | 21.458 | 17.841 | 17.015 |
| Corrected Speed (RPM/√O) | 68515 | 95453 | 76437 | 54579 | 47841 |
| Actual Speed (RPM) | 71350 | 99420 | 80360 | 57200 | 49940 |
| | | | | | |
| Turbine Expansion Ratio | 1.889 | 2.766 | 1.715 | 1.327 | 1.131 |
| Corrected Speed (rpm) | 55051 | 70942 | 44196 | 33150 | 30422 |
| % Des Corr Speed (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.043 | 0.043 | 0.043 | 0.043 | 0.290 |
| Corrected Flow (#/sec) | 0.102 | 0.120 | 0.100 | 0.077 | 0.185 |
| Turbine Efficiency (%-meas T) | 70.7 | 72.6 | 89.7 | 116.1 | 101.2 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 74.5 | 72.1 | 73.2 | 112.8 | 143.2 |
| U/V' | 0.614 | 0.641 | 0.530 | 0.540 | 0.742 |
| Load Coef | 0.937 | 0.883 | 1.599 | 1.992 | 0.919 |
| Inlet Temp (R) | 871.3 | 1018.7 | 1714.8 | 1544.3 | 1397.7 |
| Discharge Temp (R) | 770.5 | 836.6 | 1516.4 | 1417.1 | 1352.4 |
| Inlet Press (psia) | 26.933 | 38.654 | 24.491 | 19.065 | 16.215 |
| Discharge Press (psia) | 14.256 | 13.977 | 14.282 | 14.372 | 14.333 |
| | | | | | |
| Compressor Power (HP) | 4.28 | 12.58 | 3.59 | 1.15 | 1.61 |
| Eff-comprXEff-turb | 0.432 | 0.435 | 0.266 | 0.281 | 0.565 |
| Eff-turb from Eff-compr w/o HT | 59.50 | 62.84 | 46.67 | 48.60 | 78.65 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 | 1.340 | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 | 0.269 | 0.269 | 0.270 |

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.42

| | | |
|---|---|---|
| Rdg#/Hr:Mn | 66/15:11 | 67/15:20 |
| Engine Speed (RPM) | 1998 | 2010 |
| Torque (ft-#) | 156.3 | 208.4 |
| Horsepower (HP) | 59.5 | 79.8 |
| sfc (#/HP-hr) | 0.392 | 0.385 |
| Air/Fuel Ratio | 25.81 | 21.28 |
| Dry Air/Fuel Ratio | 25.46 | 20.98 |
| Rel Humidity (%) | 31 | 30 |
| Dry Bulb Temp (R) | 562.9 | 564.2 |
| Engine delta P (psi) | 1.21 | 2.55 |
| Air Rate (#/hr) | 601.8 | 654.0 |
| Fuel Rate (#/hr) | 23.315 | 30.735 |
| Fuel time (sec) | 154.4 | 117.1 |
| Fuel Temp (R) | 575.6 | 574.2 |
| Crank Case Oil Temp (R) | 691.6 | 700.4 |
| | | |
| Compressor Pressure Ratio | 1.326 | 1.497 |
| Corrected Flow (CFM) | 141.2 | 154.0 |
| Corrected Flow (#/sec) | 0.180 | 0.196 |
| Compressor Efficiency (%) | 56.1 | 59.3 |
| Compr Eff w/o .0008HT(%) | 68.6 | 69.4 |
| Inlet Temp (R) | 565.4 | 566.8 |
| Discharge Temp (R) | 650.1 | 683.8 |
| Inlet Press (psia) | 14.249 | 14.216 |
| Discharge Press (psia) | 18.898 | 21.287 |
| Corrected Speed (RPM/√O) | 62468 | 73392 |
| Actual Speed (RPM) | 65220 | 76720 |
| | | |
| Turbine Expansion Ratio | 1.247 | 1.329 |
| Corrected Speed (rpm) | 39379 | 43438 |
| % Des Corr Speed (%) | 0.00 | 0.00 |
| Vane Throat Dim. (in) | 0.290 | 0.290 |
| Corrected Flow (#/sec) | 0.239 | 0.263 |
| Turbine Efficiency (%-meas T) | 74.9 | 68.9 |
| Turbine Efficiency (%-cmpr+brg Pwr) | 106.8 | 98.8 |
| U/V' | 0.723 | 0.705 |
| Load Coef | 0.716 | 0.693 |
| Inlet Temp (R) | 1422.8 | 1618.0 |
| Discharge Temp (R) | 1362.7 | 1539.3 |
| Inlet Press (psia) | 17.686 | 18.739 |
| Discharge Press (psia) | 14.187 | 14.097 |
| | | |
| Compressor Power (HP) | 3.94 | 6.18 |
| Eff-comprXEff-turb | 0.526 | 0.523 |
| Eff-turb from Eff-compr w/o HT | 76.76 | 75.38 |
| Cp/Cv, ratio of spec heats | 1.340 | 1.340 |
| Cp (Btu/Lbm/R) | 0.270 | 0.270 |

DAT
FILMI
7-8