

AD-A123 846

FUEL CONSUMPTION REDUCTION FOR DIESEL POWER GENERATOR
SETS THROUGH THE AP. (U) AERODYNE DALLAS TX J R ARVIN
OCT 82 DAAK70-82-C-0070

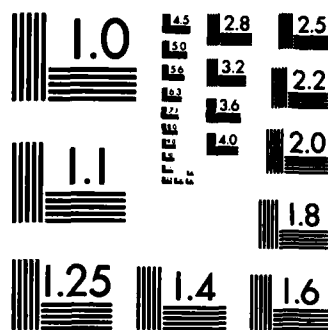
1/1

UNCLASSIFIED

F/G 10/2

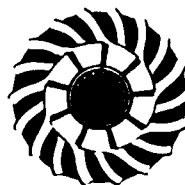
NL

										END			
										FILED			
										DTIC			



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

D



Aerodyne Dallas

ADA 123846

FINAL REPORT

CONTRACT NO. DAAK70-82-C-0070

FUEL CONSUMPTION REDUCTION
FOR DIESEL POWER GENERATOR SETS
THROUGH THE APPLICATION
OF AN ADVANCED TURBOCHARGER
OPERATING AT CONSTANT SPEED

PREPARED BY

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

DTIC
ELECTE
JAN 27 1983
S **D**
D

DTIC FILE COPY

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A123846	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Fuel consumption reduction for diesel powered generator sets through the application of an advanced turbocharger operating at constant speed		5. TYPE OF REPORT & PERIOD COVERED 3/30/82 - 10/8/82
7. AUTHOR(s) John R. Arvin		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Aerodyne Dallas 151 Regal Row, Suite 120 Dallas, Texas 75247		8. CONTRACT OR GRANT NUMBER(s) DAAK70-82-C-0070
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Mobility Equipment Research and Development Center Fort Belvoir, Virginia 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE October 1982
		13. NUMBER OF PAGES 42
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) DISTRIBUTION STATEMENT A 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 Turbocharged DED gen set		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Turbocharged diesel engine driven gen sets in the past, having not been able to respond to instantaneous zero-to-full load changes and maintain frequency within mil. std. 705B specifications. This is because of the poor turbo-charger transient response commonly called "turbo lag". A VATN (variable area turbine nozzle) turbocharger, partially developed under Army contracts DAAK70-78-C-0031 and DAAK70-80-C-0146, eliminates turbo lag.		

Calculations were made to estimate the engine operating conditions for a four cylinder turbocharged diesel engine driven, precision, 30KW-400Hz gen set. Similar calculations were made for the current, naturally aspirally, six cylinder diesel driving the same gen set. These calculations showed that the VATN feature would allow the turbo to hold a constant intake manifold pressure at all load levels thereby eliminating turbo lag. Furthermore a fuel saving of 9% or more was estimated based on the mil. std. 705B 100 hour duty cycle.

A controller was designed and built to position the turbine nozzle so as to maintain the intake manifold pressure determined from the calculations. The four cylinder engine, with the VATN turbocharger and controller, was dynamometer tested. Test data confirmed the estimated fuel savings and operation of the turbocharger-engine system.

The six cylinder diesel was removed from a GFE 30KW-400Hz, precision, gen set and replaced by the four cylinder, turbocharged engine. Transient test methods 608.1a, 619.1c, and 619.2b of mil. std. 705B were conducted on the demonstrator gen set. All compliance criteria were satisfied. It can be concluded that a DED gen set equipped with a VATN turbocharger can meet the military gen set transient requirements.

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By <i>Pex</i> DTIC Form 50	
Distribution/on file	
Availability Codes	
Dist	Avail and/or Special
<i>A</i>	



UNIVERSITY OF ALABAMA LIBRARY

31 and 1
f a sma.
TN), a
stem.

•

The turbocharger, with controller, was installed on a four cylinder diesel engine and tested at the engine manufacturer's (White Engine Co.) facility. Fuel consumption data was used to further refine the engine math model. Calculations confirmed at least a 9% fuel savings for the 30KW-400Hz gen set. The engine was then sent to Libby Welding Co. for mating with a generator and further tests.

A GFE 30KW-400Hz DED gen set, powered by the bill-of-materials six cylinder engine, was supplied to Libby by MERADCOM. Libby did all the work necessary to remove the six cylinder naturally aspired engine and replace it with the turbocharged four cylinder engine received from White Engine Co. to form the demonstrator unit. Transient gen set tests were performed by Libby. The tests were method 608.1a, method 619.1c, and method 619.2b of mil. std. 705B. The demonstrator unit exceeded all compliance requirements associated with the above three gen set tests.

From the effort of this contract, it can be concluded that a DED precision gen set equipped with a VATN turbocharger can comply with DoD transient requirements.

PREFACE

This report was prepared by Aerodyne Dallas under U.S. Army Contract DAAK70-82-0070, 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 March 1980 to September 1982, at which time the program was completed.

Special thanks go to the personnel at White Engine Co. and Libby Welding Co. for their assistance and guidance in conducting this work.

TABLE OF CONTENTS

	Page
Title.....	1
Summary.....	iii
Preface.....	iv
List of Figures.....	vi
List of Tables.....	vii
 I Introduction.....	 1
II Estimate Engine Performance.....	4
A. Current Fuel Consumption	
B. Calculated Fuel Consumption	
C. Demonstrator Gen Set Calculations	
D. Effect of Altitude	
 III Turbocharger Controller.....	 11
A. Design	
B. Fabrication	
 IV Turbocharger and Controller Testing.....	 14
 V Engine Dynamometer Testing.....	 17
A. Analysis	
B. Revised Fuel Consumption Estimate	
 VI Generator Transient Response Tests.....	 23
A. Demonstrator Gen Set Configuration	
B. Transient Electrical Tests	
 VII Conclusions and Recommendations.....	 34
A. Conclusions	
B. Recommendations	
 Appendix.....	 36

LIST OF FIGURES

	Page
1. Turbocharger crossection and nomenclature.....	2
2. Fuel consumption for existing generator sets at various loads- measured and calculated.....	7
3. Fuel consumption estimated for demo generator set at various loads.....	8
4. Compressor Map.....	9
5. Layout of generator set turbocharger controller.....	12
6. Control pressure as a function of deflection and preload.....	15
7. Compressor checkout test data.....	16
8. Engine dynamometer test data.....	18
9. Measured brake specific fuel consumption for a 226 CID engine (taken at White Engine Company) at 2000 RPM.....	19
10. Fuel consumption at various loads with revised estimate for demo generator set.....	21
11. Generator test data.....	24- 31
12. Portion of oscillograph chart.....	32- 33

LIST OF TABLES

	Page
I. Army supplied data.....	4
II. Required engine output horsepower.....	4
III. Comparison of measured and calculated fuel consumption for one 705B duty cycle.....	5
IV. Comparison of fuel usage for 30KW-400Hz gen set operating over 705B duty cycle.....	6
V. Summary of calculated engine operating points.....	10
VI. Summary of calculations relating to engine dynamometer tests and refined fuel consumption estimates.....	22
VII. Summary of calculation points used to estimate fuel savings for 60KW-60Hz, DED gen set.....	35

I. INTRODUCTION

Turbocharging of internal combustion engines can result in improved fuel economy by down-sizing and/or reducing the engine speed. The application of the turbocharger then brings the power output back to the original naturally aspirated value. Additional fuel consumption benefits can be realized for the turbocharged diesel engine due to improved air fuel ratio.

A turbocharger has been developed by Aerodyne Dallas which employs several advanced design features. These features include variable area turbine nozzles (VATN), an overhung rotor supported by two ball bearings located near the cool environment at the compressor inlet, and a self-contained lubrication system. Placing the bearings in the cool portion of the turbocharger and eliminating the need for engine lube oil, addresses the factors which most significantly contribute to turbocharger failure. The turbine variable geometry and extremely low parasitic losses associated with the ball bearing system are features which contribute to improved turbocharger performance, especially transient response. Also, the VATN feature is a more efficient method of controlling boost pressure (via turbine power output) than a wastegate.

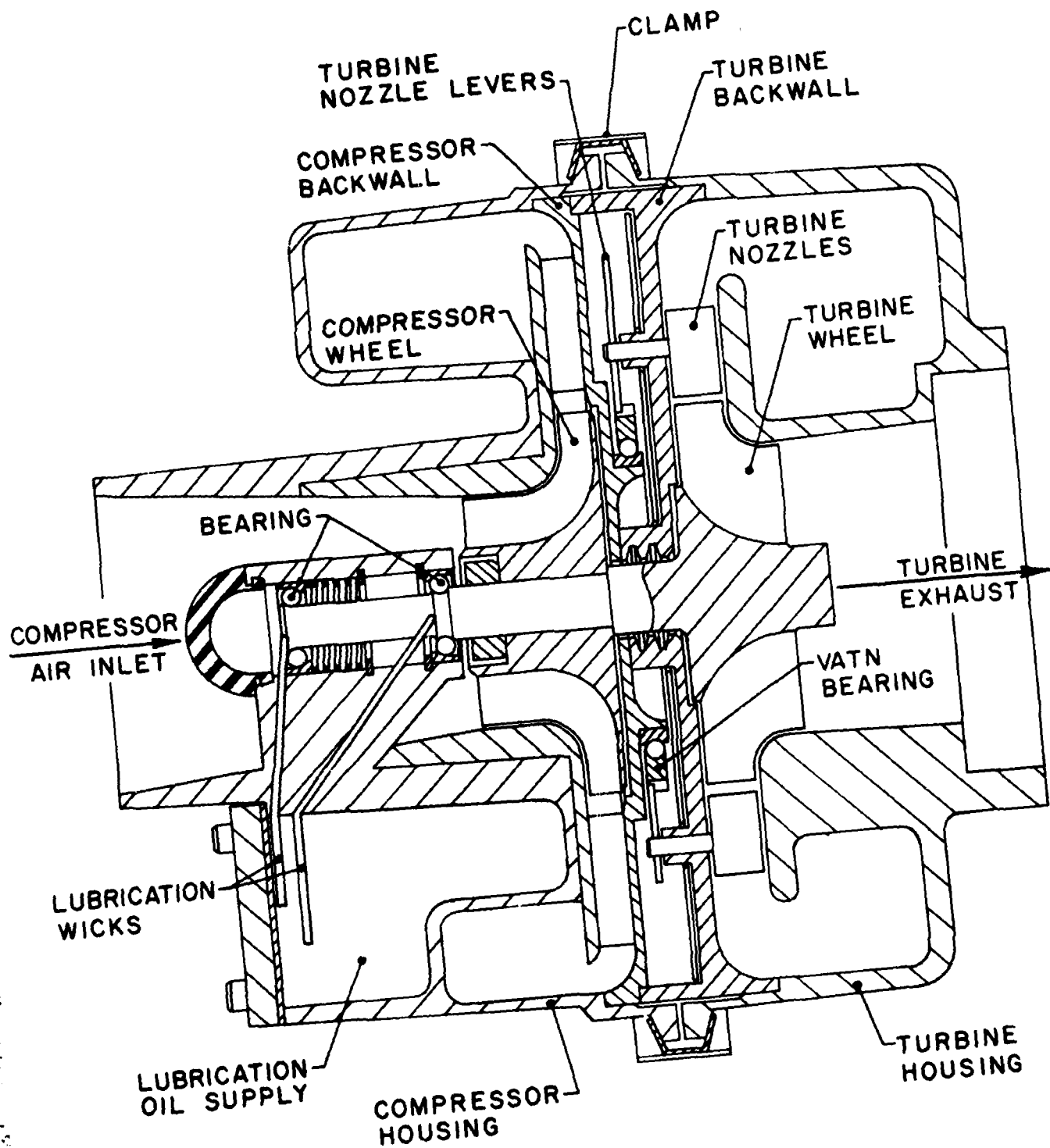
Figure 1 is a crosssectional view of the Aerodyne turbocharger with associated nomenclature. Two previous Army contracts, DAAK70-78-C-0031 and DAAK70-80-C-0146, greatly contributed to the development of this turbocharger. Based on the successful engine testing and the broad operating range of the VATN turbine, a proposal was made to Fort Belvoir to apply this turbocharger to an Army diesel engine driven (DED) generator set. The degree of turbocharging is severely limited for military DED gensets because of turbocharger lag. The poor transient response of conventional turbochargers will not allow the engine to respond to a 0 to full load transient within DoD gen set performance specifications. The VATN feature of the Aerodyne turbocharger eliminates the turbocharger lag problem. Nearly a constant boost pressure is maintained at all gen set load levels through proper control of the turbine nozzles. A program was contracted with MERADCOM, Fort Belvoir, to demonstrate that the VATN turbocharger would enable a turbocharged, 30KW-400Hz, DED gen set to satisfy the transient requirements for military gen sets. The program was to culminate with a demonstrator 30KW-400Hz gen set powered by a four cylinder diesel replacing a 6 cylinder, naturally aspirated diesel. The program elements included the following five main tasks:

- * Analysis using engine math model
- * Design and fabricate controller
- * Refurbish turbochargers and check performance of controller and turbocharger
- * Engine dynamometer test

FIGURE 1 - Turbocharger Crossection and Nomenclature



Aerodyne Dallas
151 Regal Row
Suite 120
Dallas, Texas 75247
(214) 688-1100



* Generator electrical tests as described in Military standard 705B:

Method 608.1a

Method 619.1c

Method 619.2b

Successful compliance with DoD gen set transient response requirements will enable the military to realize the benefits of the turbocharged diesel. These benefits include a smaller, lighter, more fuel efficiency engine. There is the potential for using a family of engines over a wide range of gen set sizes. This would have a favorable impact on inventory size, number of items in inventory, logistics, and possibly acquisition cost.

The purpose of this report is to present the work performed under Army contract DAAK-70-82-0070 as applied to the above tasks. The report organization follows these tasks.

II ESTIMATE ENGINE PERFORMANCE

The purpose of this task was to estimate engine performance at various full load air/fuel ratios (A/F) and to select a range of boost pressures which give the desired A/F values. Also, as part of this task, the effect of altitude was assessed and the effect of allowing the turbo speed to decrease at low engine loads was investigated.

CURRENT FUEL CONSUMPTION

MERADCOM, at Fort Belvoir, provided electrical generator efficiencies as a function of load and fuel consumption data for several current DED generator sets of interest. Table 1, below, lists this data and also gives the total fuel used during one mil. std. 705B duty cycle (also defined in table 1).

TABLE 1 - Army supplied data

	% of full load					Total for 705B duty cycle
	0	25	50	75	100	
generator efficiency	0	65%	74%	79%	82%	
Mil Std 705B duty cycle time, hr	4	24	24	24	24	100 hr
gal/hr (15KW, 60 Hz)	0.59	0.89	1.18	1.48	1.77	130.0 gal
gal/hr (30KW, 60 Hz)	1.01	1.52	2.03	2.53	3.04	222.9 gal
gal/hr (30KW, 400 Hz)	1.37	1.88	2.39	2.89	3.40	258.9 gal
gal/hr (60KW, 60 Hz)	2.04	3.05	4.08	5.10	6.13	448.8 gal

CALCULATED FUEL CONSUMPTION

The analytical work for this task was done using a computerized math model partially developed under the two previously mentioned Army contracts. The electrical generator efficiencies shown in Table I were used to calculate the engine output power required for all gen sets considered. Table II gives the horsepower output required for the 15 and 30 KW gen sets.

TABLE II - Required engine output horsepower

	% of full load				
	0	25	50	75	100
15KW	0	7.73	13.59	19.10	24.53
30KW	0	15.46	27.18	38.20	49.06

A multiplying factor was applied to the math model indicated thermal efficiency correlation such that the calculated total fuel usage for one 705B cycle of the 15KW-60Hz, and the 30KW-60Hz gen sets was near the values shown in table I. The final multiplying factor was 0.9306. Table III shows a comparison of the measured and calculated values of fuel consumption in terms of gallons of fuel for one mil. std. duty cycle.

TABLE III- Comparison of measured and calculated fuel consumption for one 705B duty cycle

GEN SET	MEASURED gal	CALCULATED gal	$\frac{\text{CALC}}{\text{MEAS}}$	ERROR
15KW-60Hz	130.0	127.5	0.9808	- 1.92%
30KW-60Hz	222.9	230.0	1.0319	+ 3.19%
30KW-400Hz	258.9	246.1	0.9506	- 4.49%

Table V at the end of this section of the report list several of the parameters of interest taken from each of the calculated points. Calculation numbers 1 through 5 are for the current 15KW-60Hz gen set, numbers 6 through 10 are for the current 30KW-60Hz gen set, and numbers 11 through 15 are estimates of the 30KW-400Hz gen set. The fuel rates are based on a fuel density of 7.311 pounds mass per gallon.

DEMONSTRATOR GEN SET CALCULATIONS

Calculation points 16, 23, and 28 (see table V) show that the full load minimum fuel consumption, for the three air/fuel ratios (A/F) considered, occurred at A/F = 32.0. The three A/F values were 28, 32, and 36; the corresponding fuel flows were 3.064, 2.991, and 2.997 gallons/hour respectively. A/F of 28 and 32 were chosen to define the range of interest for this program. The compressor pressure ratios (P2/P1) were 1.298, 1.490, and 1.748 for the three full load A/F values. Calculation points 16 through 20 are for the various load levels for the gen set with a turbocharger controller holding the turbocharger at a constant compressor discharge pressure, P2, as the load was reduced from 100 to 0%. As will be seen in a later section of this report, the simplicity of the turbocharger controller hardware allowed the boost pressure to drop slightly with gen set load. Calculation points 23 through 27 are similar to 16-20 except the turbocharger boost is set to give an A/F of 32 at full load.

The effect of holding the turbine vanes in a fixed position for loads below 50% were investigated for the condition where the full load A/F was 28. The five calculation points for this control mode are 16, 17, 18, 21, and 22 in table V. From points 21 and 22 it can be seen that the turbocharger pressure ratio (P2/P1) dropped as the load decreased with the vanes fixed. It was felt that a small benefit might be derived from improving the engine ΔP (intake manifold pressure, P2, minus exhaust manifold pressure, P3). A negative engine ΔP is reflected as additional work required by the piston to pump the engine gas flow against the pressure gradient across the engine. Table IV, below, lists the fuel consumption comparisons.

TABLE IV - Comparison of fuel usage for 30KW-400Hz
gen set operating over 705B duty cycle

TABLE V POINT NO.	GEN SET AND OPERATION DESCRIPTION	GALLONS	CALC MEAS
	Measured current gen set with 298CID	258.9	
(11-15)	Calculated current gen set with 298CID	246.1	.9506
(16-20)	Calculated for 28 A/F, const P2, 226CID	221.5	.8555
(16-18, 21,22)	Calculated for 28 A/F, const vanes 50-0% 226CID	221.3	.8548
(23-27)	Calculated for 32 A/F, const P2, 226CID	221.2	.8544

From table IV it can be seen by comparing the calculated current fuel usage to that for the constant P2, 28 A/F, case that an estimated 10.0% improvement in fuel consumption may be realized over the mil. std. 705B duty cycle. Also the fuel consumption for the const P2 and 28 A/F and 32 A/F are the same within 0.15%. Furthermore, holding the turbine vanes fixed from 50% load down to 0 load would only reduce the calculated fuel usage less than 0.10%. Figure 2 graphically presents the measured and calculated fuel consumption for the various current gen sets considered in this study as a function of load. Figure 3 shows the fuel consumption estimated for the demonstrator gen set operating with the turbocharger controller set to give a full load A/F of 28. The data in figure 2 is also shown subdued in figure 3. The shaded area between the circle-symbols line and the actual data for the 30KW-400Hz gen set depicts the estimated fuel savings which can be achieved by substituting a turbocharged, 4 cylinder, 226 CID diesel for a naturally aspirated, 6 cylinder, 298 CID diesel engine.

Figure 4 illustrates the compressor operating point as the full load A/F ratio is varied from 28 to 32 to 36 for the 30KW-400Hz gen set. The compressor trim, or size, depicted by the map in figure 4 is the same as the turbocharger compressor used in the previous contract (DAAK70-80-0146).

EFFECT OF ALTITUDE

The effect of altitude was determined by calculating operating points at 5000 and 8000 feet, points 29 and 30 in table V. These points are also spotted on the compressor map, figure 4. In calculating the two altitude points, it was assumed that full load was maintained, and that the turbocharger controller would maintain a constant difference between intake manifold and ambient pressure ($P_2 - P_{amb}$). This gave a reduction in A/F from 28 at sea level to 23.4 at 5000 feet and to 20.4 at 8000 feet. It was therefore concluded that constant load could be maintained up to altitude of 8000 feet, since the A/F did not drop below 18.

This concluded the analytical study effort.

FIGURE 2 - FUEL CONSUMPTION FOR EXISTING GENERATOR SETS
AT VARIOUS LOADS - MEASURED AND CALCULATED

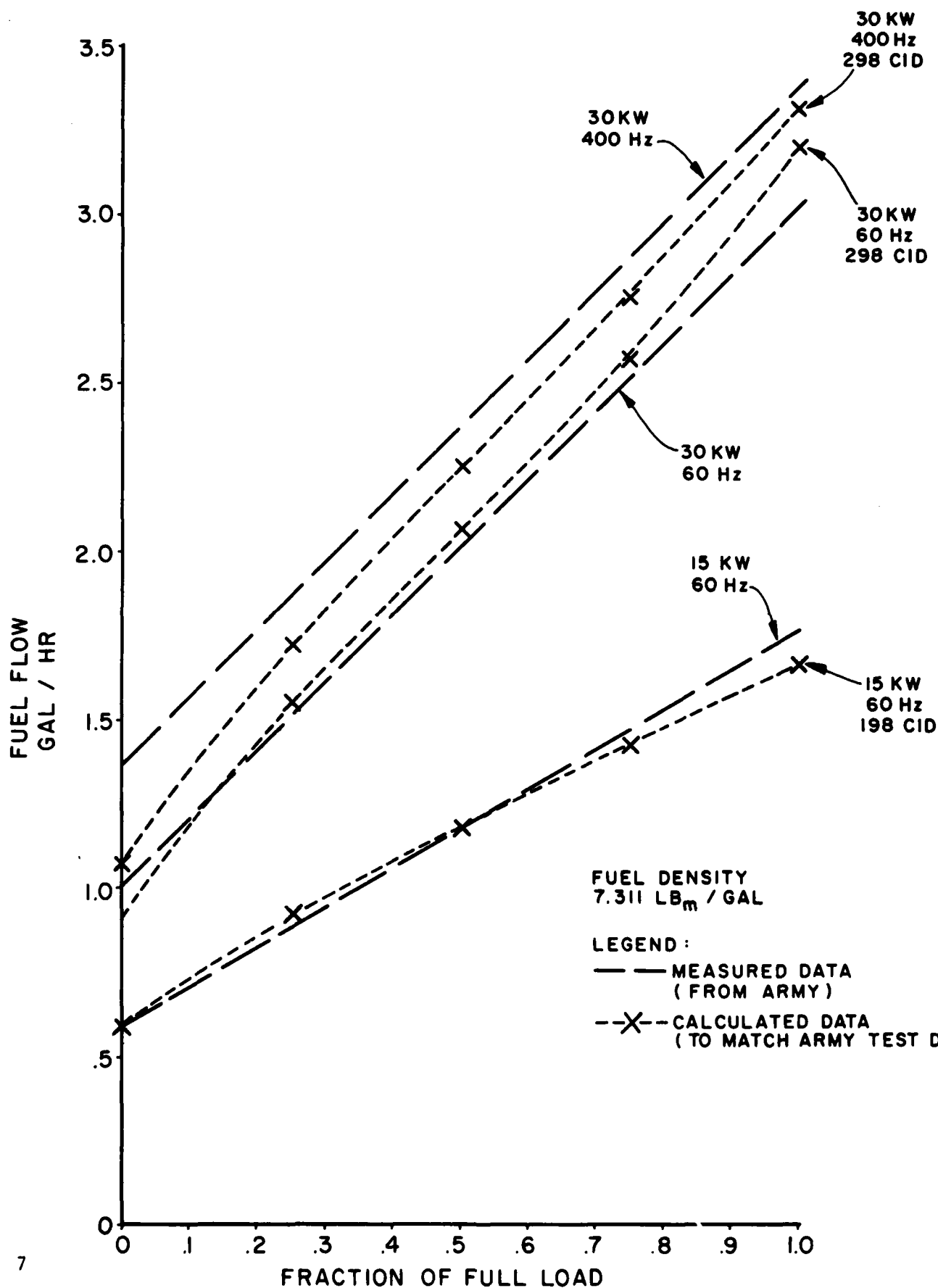


FIGURE 3- FUEL CONSUMPTION ESTIMATED FOR DEMO
GENERATOR SET AT VARIOUS LOADS

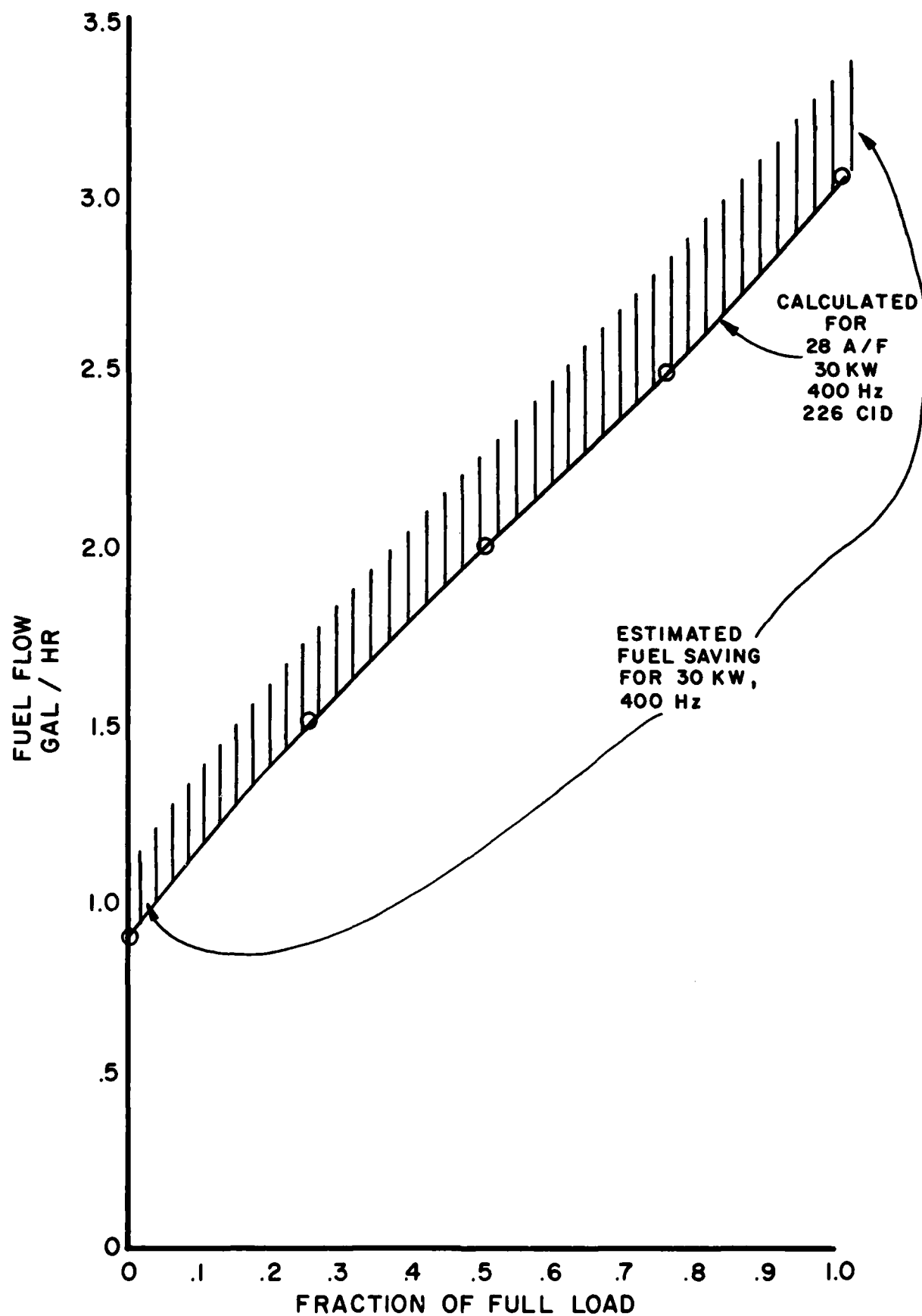


FIGURE 4 - COMPRESSOR MAP

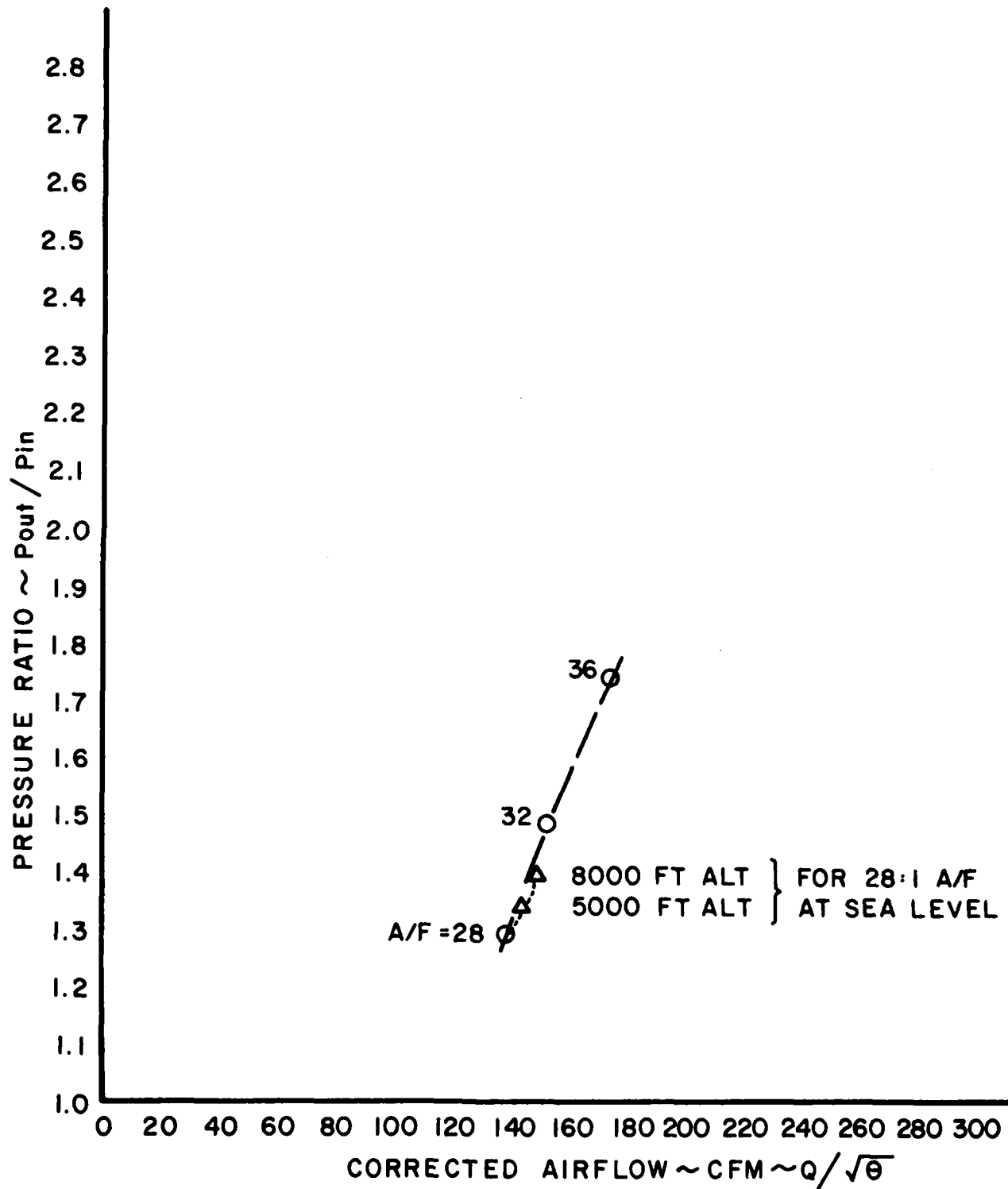


TABLE V - Summary of Calculated Engine Operating Points

CALC NO.	DISP In ³	NE RPM	ALT Ft.	P2/P1	A/F	FUEL FLOW Gal/Hr.	POWER BHP	LOAD FRACTION %	WITH MULT
1	198	1800	0	N/A	34.0	1.675	24.5	100.	.9306
2					39.9	1.430	19.1	75.	
3					48.2	1.183	13.6	50.	
4					61.7	0.924	7.7	25.	
5					95.7	0.596	0.	0.	
6	298	1800	0	N/A	26.7	3.213	49.1	100.	
7					33.2	2.586	38.2	75.	
8					41.3	2.075	27.2	50.	
9					55.1	1.558	15.5	25.	
10					95.7	0.897	0.	0.	
11	298	2000	0	N/A	28.3	3.322	49.1	100.	
12					34.1	2.760	38.2	75.	
13					41.7	2.258	27.2	50.	
14					54.3	1.733	15.5	25.	
15					87.9	1.072	0.	0.	
16	226	2000	0	1.298	28.0	3.064	49.1	100.	
17					34.3	2.506	38.2	75.	
18					42.7	2.013	27.2	50.	
19					57.3	1.502	15.5	25.	
20					98.1	0.877	0.	0.	
21	226	2000	0	1.222	54.7	1.499	15.5	25.	
22				1.153	93.1	0.844	0.	0.	
23	226	2000	0	1.490	32.0	2.991	49.1	100.	
24					38.2	2.502	38.2	75.	
25					47.2	2.028	27.2	50.	
26					62.1	1.537	15.5	25.	
27					101.4	0.937	0.	0.	
28	226	2000	0	1.748	36.0	2.997	49.1	100.	
29	226	2000	5000	1.358	23.4	3.228	49.1	100.	
30			8000	1.401	20.4	3.422	49.1	100.	

III TURBOCHARGER CONTROLLER

The next task was to design a control device which would maintain boost pressure at the levels calculated and reported in the previous section.

DESIGN

The design of the controller was kept as simple as possible. Past experience at Aerodyne in developing a simple controller for automotive application was drawn upon. The controller design is a piston and spring arrangement which maintains a nearly constant difference in pressure between the intake manifold and ambient. The final design is shown in Figure 5, Aerodyne drawing 2638. Intake manifold pressure, P_2 , is vented to the chamber formed by piston (2) and cover plate (3) in drawing 2638. Between the opposite side of the piston and the adjustable screw (8) another chamber is formed; this chamber is vented to ambient. Piston rod (9) is connected to the turbocharger vane control rod. When the $P_2 - P_{amb}$ pressure difference acting over the piston area develops a force greater than that applied by spring (5) to the piston, then piston rod moves to the left in figure 5. The nuts (12) on the end of the piston rod (9) limit the travel to the left and the position of bolt (13) limits the travel to the right. Screw (8) was designed long enough to provide a range of spring preload values by simply compressing the spring. The length available for the spring was defined such that a long spring with a low spring constant could be used. This tended to minimize the effect of piston position on control pressure. The following equation gives the relationship of the various parameters:

$$P_2 - P_{amb} = A_p \cdot K (L_f - L_{pl} + \text{vane travel}) \quad (\text{eqn 1})$$

Where * P_2 is the desired intake manifold pressure, control pressure

* P_{amb} is ambient pressure

* A_p is piston area

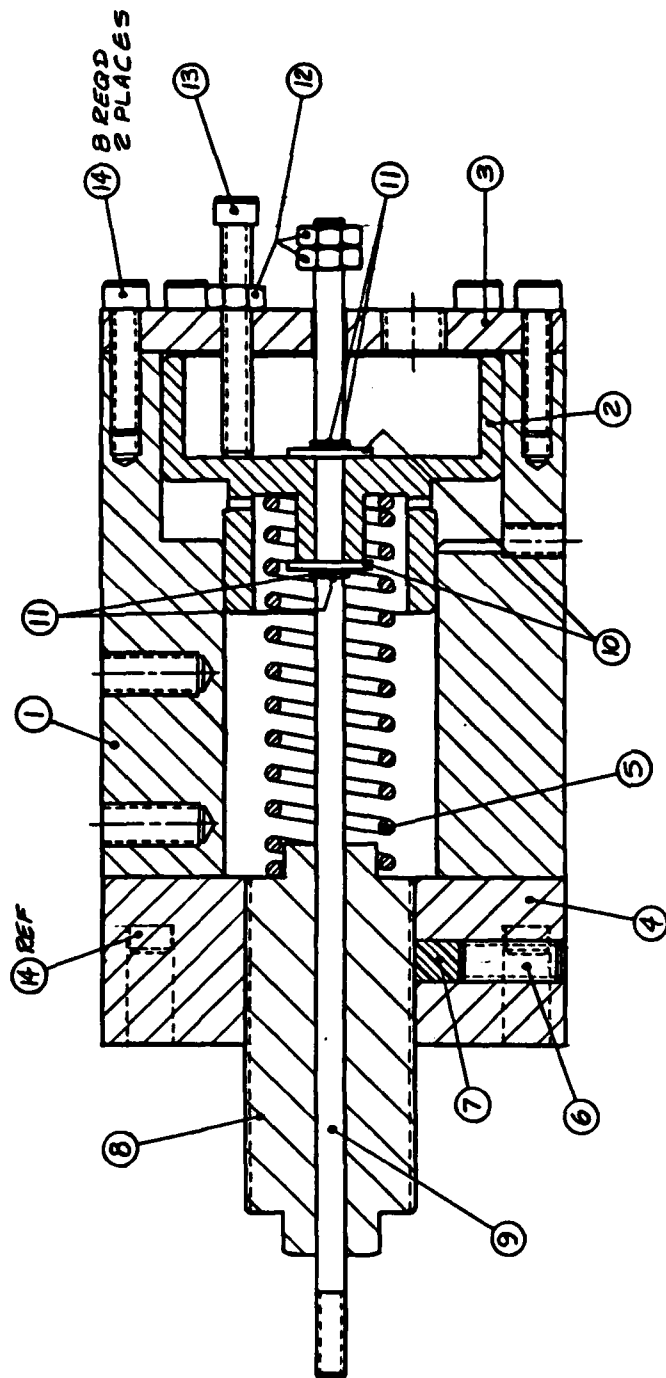
* K is spring constant, force/change in length

* L_f is spring free length

* L_{pl} is length of spring after being preloaded by screw (8)

* Vane travel is the length of travel of the vane control rod from the full closed position

From the above equation it can be seen that P_2 , the control pressure, can be changed by turning screw (8) thereby changing $L_f - L_{pl}$. Also, during operation, the control pressure will be higher with the vanes open (large vane travel value) than closed (small vane travel). The vanes move toward the open position as the load increases. Screws (12) on the end of rod (9) and screw (13) serve as mechanical stops which can be adjusted to limit the maximum and minimum travel of rod (9). This sets the vane open and closed positions. Screw (13) would be used



14	16	BOLT (8-32 x .75 LONG)
13	1	BOLT (10-32 x 1.38 LONG)
12	3	NUT (10-32)
11	4	KEEPER (TRU-ARC 5103-18)
10	2	WASHER (A/D 2637)
9	1	PISTON ROD (A/D 2636)
8	1	ADJUSTMENT SCREW (A/D 2635)
7	1	PLUG (A/D 2634)
6	1	SET SCREW (1/4-20 x .625 LONG)
5	1	SPRING (LCO6710 MW)
4	1	COVER PLATE (A/D 2633)
3	1	COVER PLATE (A/D 2623-2)
2	1	PISTON (A/D 2621-2)
1	1	HOUSING (A/D 2622)

ITEM	QTY	DESCRIPTION
14	16	BOLT (8-32 x .75 LONG)
13	1	BOLT (10-32 x 1.38 LONG)
12	3	NUT (10-32)
11	4	KEEPER (TRU-ARC 5103-18)
10	2	WASHER (A/D 2637)
9	1	PISTON ROD (A/D 2636)
8	1	ADJUSTMENT SCREW (A/D 2635)
7	1	PLUG (A/D 2634)
6	1	SET SCREW (1/4-20 x .625 LONG)
5	1	SPRING (LCO6710 MW)
4	1	COVER PLATE (A/D 2633)
3	1	COVER PLATE (A/D 2623-2)
2	1	PISTON (A/D 2621-2)
1	1	HOUSING (A/D 2622)

AERODYNE DALLAS

VATN CONTROLLER
GENERATOR SET USE

drawn	date	chd	date	approved	date
ETS	6/21/62				
inst		scale	2/1	dwg no	2638

FIGURE 5 - LAYOUT OF GENERATOR SET
TURBOCHARGER CONTROLLER

to increase the minimum vane position for calculation points 21 and 22 in Table V.

FABRICATION

The body, cover plates, and piston were machined from aluminum. The adjustable screw (8) was machined from mild steel. The remaining parts were purchased "off-the-shelf".

A spring was selected to give the range of boost pressures needed for 28 to 32 full load A/F. These pressures were 4.3 and 7.2 psig respectively. The spring was selected from the Lee Spring Company 1982 catalog. The Lee stock number is LC-067J-10. The physical characteristics are as follows:

- * free length = 3.0 inches (L_f in equation 1)
- * spring rate = 10 lbf/in (K in equation 1)
- * solid height = .883 inches (fully compressed spring)

IV TURBOCHARGER AND CONTROLLER TESTING

Bench tests on the controller were made in order to determine the change in control pressure as a function piston rod movement (spring deflection) and preload. Preload was documented as the length of the adjustable screw (8) exposed outside the cover plate (4). Figure 6 presents the bench test data for two adjustable screw (8) preload positions. These two positions approximately match the 4.3 and 7.2 psig control pressures previously mentioned. When the amount of screw (8) thread exposed was changed from 1.195 inches to 0.495 inch, the term $L_f - L_{p1}$ in equation 1 was increased by 0.700 inch thereby increasing the control pressure as shown in figure 6. At a given position of screw (8), say 0.495 inches of thread exposed, the data in figure 6 shows how the control pressure increases as the rod moves from 0 to 0.300 inches. This movement is synonymous with "vane travel" in equation 1.

Little refurbishment was needed to bring the turbochargers to working order. New turbine housings were made in order to eliminate holes left from instrumentation during the previous contract. One of the two turbochargers required a new turbine backwall. This was also due to instrumentation from the previous contract. Brief tests were made to confirm the compressor operation. One of the output data sheets is shown in figure 7. Mass flow rate to the turbine was not measured. The data points in figure 7 are near the "backbone" of the map. By comparing the compressor volumetric flow, pressure ratio, corrected speed, and efficiency to the compressor map in figure 4, it can be seen that the Army turbocharger compressor performance was the same as the map.

FIGURE 6 - CONTROL PRESSURE AS A FUNCTION
OF DEFLECTION AND PRELOAD

LEE SPRING CATALOG NUMBER LC-067J-10

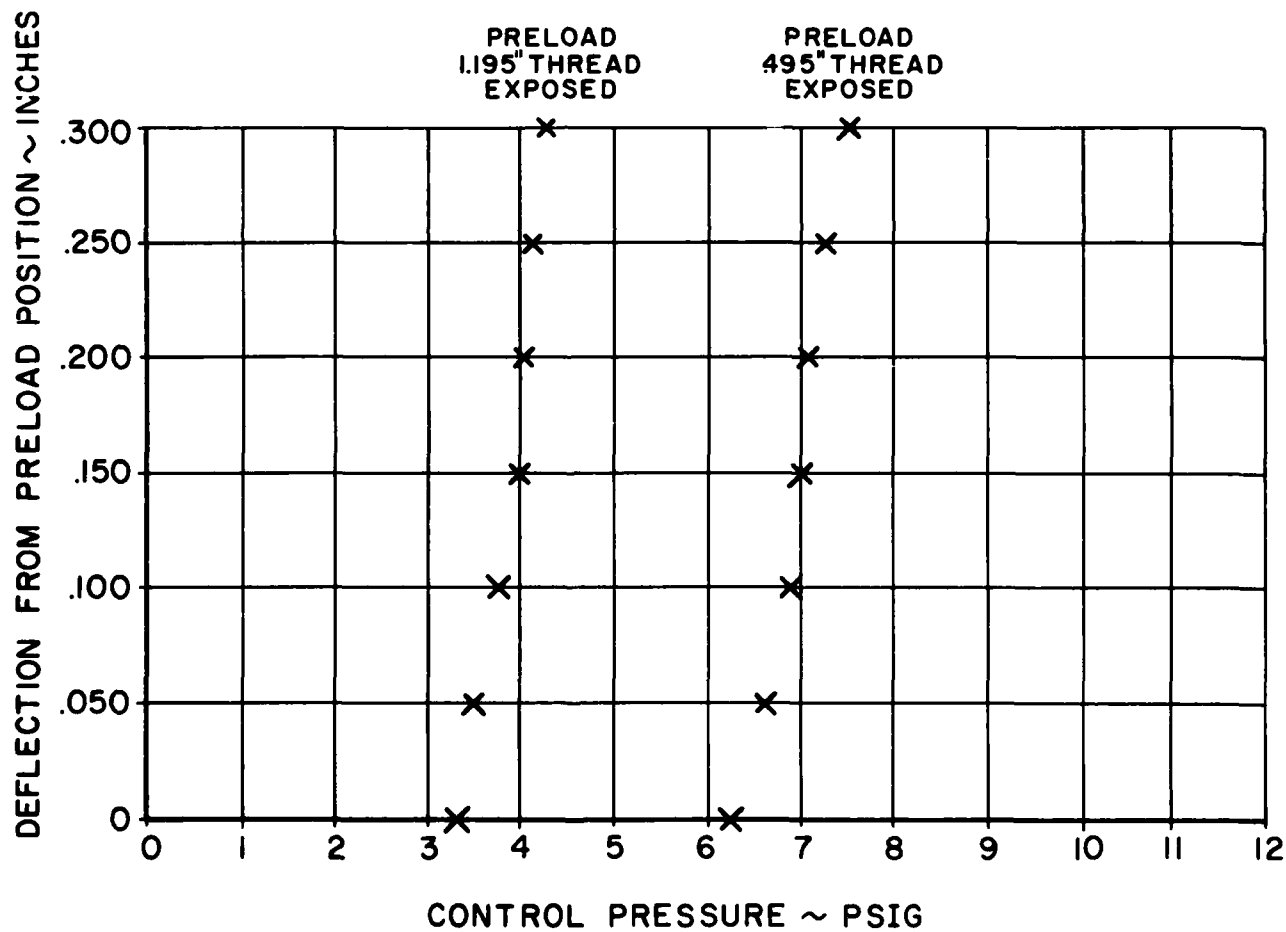


FIGURE 7 - Compressor Checkout Test Data

TIME and DATE are 04:05:14:43:36					
S/N 69A ARMY .250/119					
barometer is 29.46					
Rdq#	5	6	7	8	9
Time (Hr:Mn)	14:55	15:02	15:13	15:20	15:27
Barometer (psi)	14.466	14.466	14.465	14.465	14.465
C O M P R E S S O R					
Vol Flow (scfm)	107.9	141.3	161.1	186.3	199.6
Corr Mass Flow, W/O/D (#/sec)	0.1375	0.1801	0.2053	0.2374	0.2544
Pressure Ratio, Rc	1.3495	1.4927	1.6604	1.8714	2.1633
Corr Speed, N/O (rpm)	59774	70547	80149	90501	100196
Eff (%)	72.17	72.75	72.03	71.02	69.72
Eff, w/o .0008HT (%)	77.20	76.36	74.89	73.31	71.65
FC, V/U _m -in	0.5421	0.6008	0.6011	0.6142	0.5922
LC, DH'/Ut ²	0.5238	0.5091	0.5042	0.4953	0.5042
Corr Mass Flow, W/O/D (%des)	46.2	60.5	69.0	79.8	85.5
Corr Speed, N/O (%des)	59.8	70.5	80.1	90.5	100.2
Act Speed, N (rpm)	60820	71840	81850	92630	102960
Tin (deg R)	537.0	537.9	540.9	543.4	547.7
Tout (deg R)	603.6	627.6	658.1	693.6	741.7
Pin (psia)	14.198	14.122	14.070	14.006	13.971
Ps diff 3/Pin	1.0196	1.0250	1.0288	1.0336	1.0363
Ps diff 4+/Pin	1.0191	1.0246	1.0283	1.0331	1.0358
Pout (psia)	19.160	21.080	23.362	26.212	30.224
T U R B I N E					
Expansion Ratio, Re	1.3184	1.4572	1.6048	1.8088	2.0325
Corr Speed, N/O (rpm)	49795	56315	61555	66511	70278
Corr Speed, N/O (%des)	82.1	92.8	101.4	109.6	115.8
Vane Throat Dim. (in)	0.3000	0.3000	0.3000	0.3000	0.3000
Mass Flow, (#/sec)	0.0000	0.0000	0.0000	0.0000	0.0000
Corr Mass Flow, W/O/D (Eq#/sec)	0.0000	0.0000	0.0000	0.0000	0.0000
Eff (% meas DT)	41.22	72.63	69.93	68.05	64.79
Eff (% compr+brq+windq)	\$\$\$\$\$\$\$\$	\$\$\$\$\$\$\$\$	\$\$\$\$\$\$\$\$	\$\$\$\$\$\$\$\$	\$\$\$\$\$\$\$\$
U/V	0.8228	0.8023	0.7870	0.7653	0.7442
Load Coef	0.3045	0.5642	0.5644	0.5810	0.5849
Tin (degR)	773.8	844.1	917.1	1006.1	1113.3
Tout (degR)	749.8	782.5	837.7	902.4	985.9
Pin (psia)	18.950	20.818	22.753	25.432	28.315
Ps rotor in/Pin	0.7635	0.6951	0.6359	0.5690	0.5111
Pout (psia)	14.374	14.286	14.178	14.060	13.931
P O W E R B A L A N C E					
Compr Power (hp)	3.112	5.493	8.184	12.139	16.819
Turb Power (hp)	0.000	0.000	0.000	0.000	0.000
Brq Oil DT (degF)	0.1	0.2	0.2	0.3	0.2
Brq Oil DT Power	0.000	0.000	0.000	0.000	0.000
Brq Frctn Eqn Power	0.000	0.000	0.000	0.000	0.000
Compr windage (hp)	0.0160	0.0247	0.0355	0.0505	0.0717
Turb windage (hp)	0.0017	0.0025	0.0035	0.0047	0.0063
Power bal error (%)	\$\$\$\$\$\$\$\$	\$\$\$\$\$\$\$\$	\$\$\$\$\$\$\$\$	\$\$\$\$\$\$\$\$	\$\$\$\$\$\$\$\$

V ENGINE DYNAMOMETER TESTING

Engine dynamometer testing was conducted by White Engines Inc, the manufacturer of the engine. The test engine is model D2300-T. This engine employs more recent technology than the D198ER: the four cylinder diesel engine normally used for DoD gen set applications. The salient features of the D2300-T are as follows:

- * displacement - 226. in ³
- * bore and stroke - 4 x 4.5 inches
- * four cylinder, open chamber, diesel
- * 16:1 compression ratio

The engine was tested in a "stripped" configuration. White Engines recommended a value of 6.5 horsepower to account for the difference between the stripped configuration and the installed configuration as applied to a gen set operating at 2000 rpm. The engine was fitted with a precision fuel pump capable of controlling the engine to the DoD specifications. Figure 8 is the engine dynamometer test data. Numbers were assigned to each operating point, item 1 figure 8. The BSFC (brake specific fuel consumption), item 12 in figure 8, was plotted verses BHP (brake horsepower), item 5 in figure 8, and presented as figure 9.

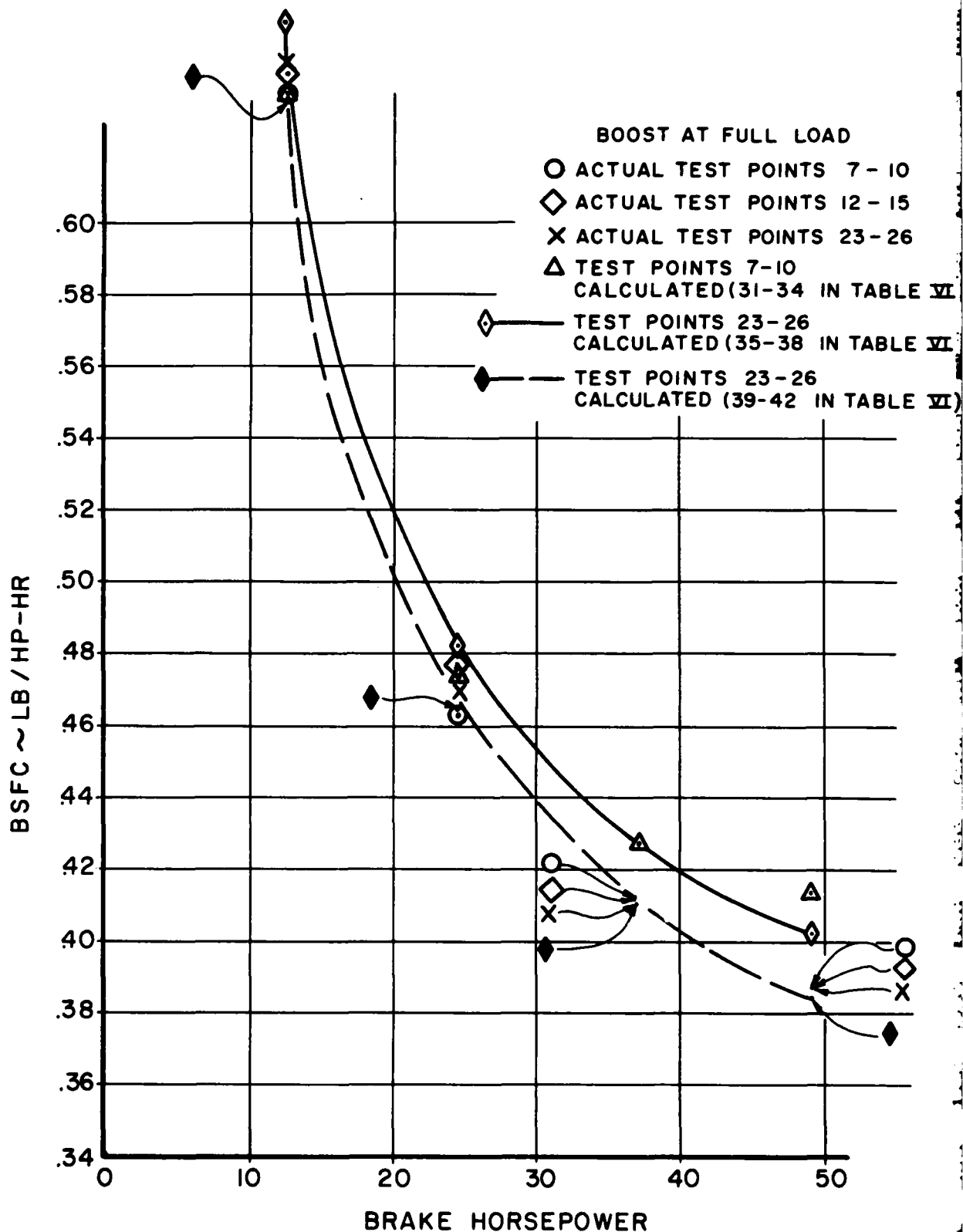
ANALYSIS

Engine operating points were calculated using the same computerized math models as discussed in section II of this report. The results of these calculations are tabulated in table VI at the end of this section of the report. Calculation numbers 31 through 34 correspond to engine dynamometer test point numbers 7 through 10. Likewise, calculation number 35 through 38 correspond to point number 23 through 26 in figure 8. As can be seen from table VI the multiplying factor on indicated thermal efficiency was 0.9306 for calculations 31-38: the same value as was used for the analytical work reported in section II. The BSFC, power, and load fraction values listed in table VI were all adjusted to reflect the 6.5 BHP adjustment to account for the difference between the installed and stripped engine. Each calculation was actually run at 6.5 BHP less than the value in table VI. Then the BSFC was adjusted. The BSFC values are shown in figure 9 as triangle and diamond symbols. A new multiplying factor on indicated thermal efficiency was determined which allowed the calculated data (points 39-42) for test points 23-26 to match the test data very closely. The new multiplier was 0.9678; 4% greater than the 0.9306 value deduced from D198ER and D298ER diesel engine driven gen set fuel consumption measurements. Calculation points 39 through 42 are also plotted in figure 9. The solid line as compared to the dashed line in figure 9 shows the effect of the change in the multiplying factor. Also, it can be seen that the dashed line closely fits the data for test points 23-26. The shaded in diamonds are the symbols for the dashed line.

FIGURE 8 - ENGINE DYNAMOMETER TEST DATA

X-29.3		MODEL 0-2322T		SERIAL NO. 153450437		DATE OF TEST 10-20-82		TEST NO. 15		PROJ. NO. 8		SHIP NO. 106-1		COMP. DATE 2005		SHEET NO. 4	
ENGINE TEST SHEET		ENGINE NO. 082-133		SERIAL NO. 40-3056552		PRESS. 2000 PSI		STATIC TIMING 3.0		OPERATION 21		OBJECT OF TEST		Aerodyne Turboelectric			
21		22		23		24		25		26		27		28		29	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2		3		4		5		6		7		8		9	
1		2															

FIGURE 9- MEASURED BRAKE SPECIFIC FUEL CONSUMPTION
FOR A 226 CID ENGINE (TAKEN AT WHITE
ENGINE COMPANY) AT 2000 RPM



REVISED FUEL CONSUMPTION ESTIMATE

Having refined the math model to match the engine dynamometer data (subject to the 6.5 BHP correction), the model was once again executed to estimate the fuel consumption of the demonstrator, 30KW-400Hz gen set. The new multiplying factor on indicated thermal efficiency was used and, at each load point, the intake manifold pressure measured on the engine dynamometer was also employed rather than a constant value. (See figure 8, item 24). These calculation results are included in table VI as calculation points 43 through 47. The revised fuel consumption for one mil. std. 705B 100 hour duty cycle is 212.0 gallons as compared to 221.5 from section II of the report. The calculated value for the current 6 cylinder D298ER engine is 246.1 gallons: the measured value for the current engine is 258.9 gallons. Figure 10 is a copy of figure 2 but with the revised demonstrator estimates included i.e. calculation points 43-47 from table VI.

One other calculation was run to estimate the operating conditions at full rated load, 8000 foot altitude, on a hot day (std day temperature + 60 F); see point 48 in table VI. The A/F ratio dropped from 32.3 to 22.8 and the fuel consumption increased from 2.879 to 3.115 gallons/hours. The A/F of 22.8 should be adequate to run full load.

As an appendix to this report, copies of the computer output for calculation points 43-48 have been included for those readers who may wish more detail than is contained in table VI.

FIGURE 10- FUEL CONSUMPTION AT VARIOUS LOADS
WITH REVISED ESTIMATE FOR
DEMO GENERATOR SET

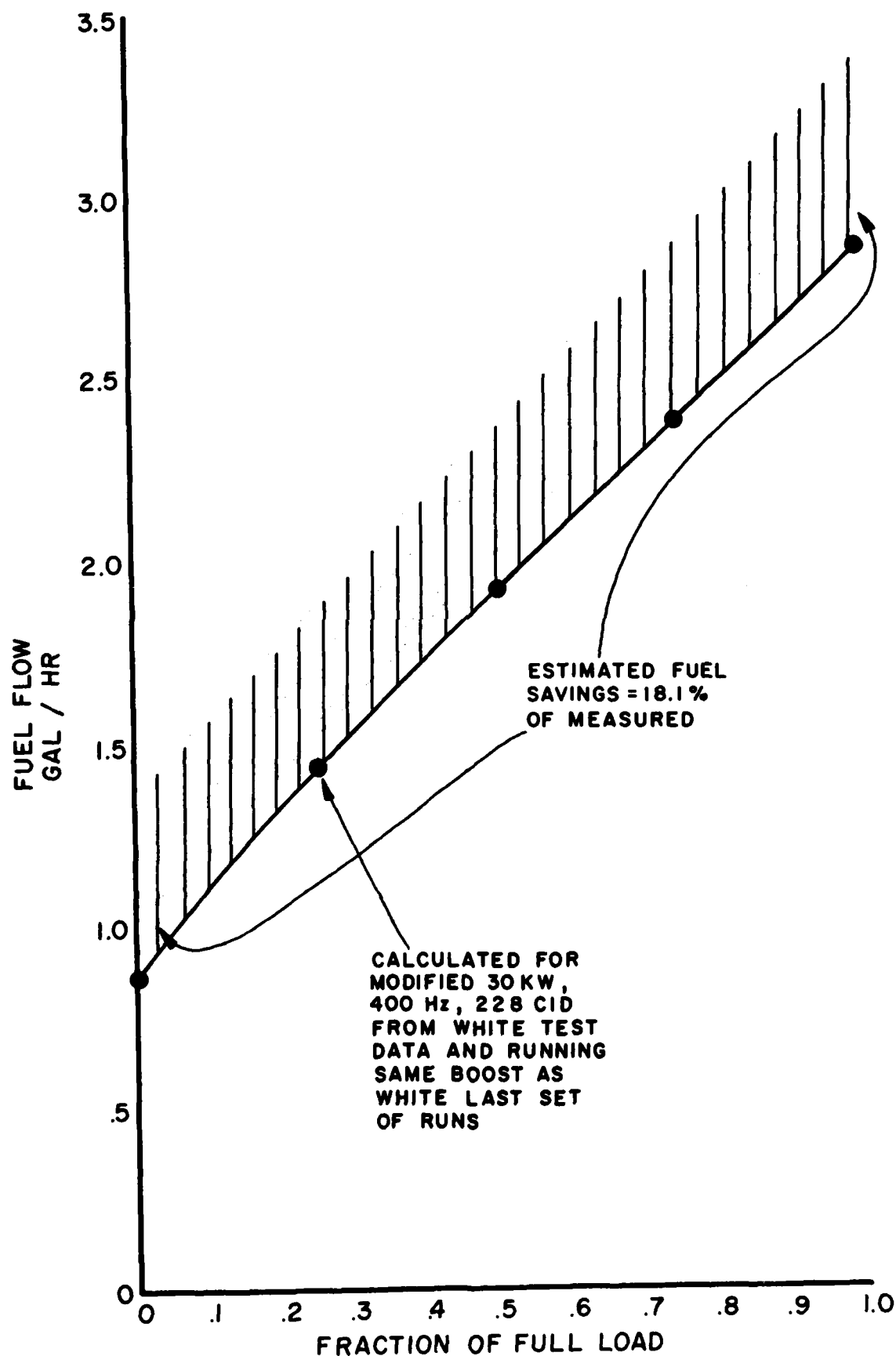


TABLE VI - Summary of Calculations Relating to Engine Dynamometer
Test and Refined Fuel Consumption Estimates

CALC NO.	DISP In ³	NE RPM	ATL Ft.	P2/P1	A/F	FUEL FLOW Gal/Hr.	ADF POWER BHP	ADJ LOAD FRACTION %	η ITH MULT	ADJ BSFC LB/ HP-Hr	TEST POINT NO.
31	226	2000	0	1.246	27.7	2.764	49.0	100.	.9306	.4124	7
32				1.200	34.5	2.158	37.0	73	.9306	.4265	8
33				1.190	46.3	1.599	24.5	45.	.9306	.4764	9
34				1.176	68.9	1.068	12.3	20.	.9306	.6365	10
35	226	2000	0	1.452	32.2	2.693	49.0	100	.9306	.4018	23
36				1.418	39.4	2.158	37.0	73	.9306	.4265	24
37				1.376	51.5	1.614	24.5	45	.9306	.4816	25
38				1.366	74.6	1.102	12.3	20	.9306	.6569	26
39	226	2000	0	1.452	33.2	2.587	49.0	100	.9678	.3859	23
40				1.418	40.6	2.079	37.0	73	.9678	.4108	24
41				1.376	53.0	1.557	24.5	45	.9678	.4645	25
42				1.366	77.1	1.067	12.3	20	.9678	.6357	26
									non-adj	non-adj	
43	226	2000	0	1.438	32.3	2.879	49.1	100	.9678	.4296	
44				1.404	38.0	2.410	38.2	75	.9678	.4612	
45				1.364	46.1	1.942	27.2	50	.9678	.5220	
46				1.354	61.0	1.458	15.5	25	.9678	.6896	
47				1.354	102.7	0.866	0	0	.9678	-	
48	226	2000	8000								
				+ 1.590	22.8	3.115	49.1	100	.9678	.4637	

VI GENERATOR TRANSIENT RESPONSE TESTS

Having completed the dynameter testing, the engine was shipped to the Libby Welding Co. Inc, with the Aerodyne turbocharger and controller installed.

DEMONSTRATOR GEN SET CONFIGURATION

A GFE 30KW-400Hz precision gen set was shipped to Libby from Fort Belvoir. Libby removed the D298ER, six cylinder diesel engine, made the necessary modifications, and installed the four cylinder engine in place of the six cylinder engine. This included lengthening the shroud which ducts air into the radiator to compensate for the difference in engine length of approximately 10 inches. Also, as a small "add-on" to the contract, rubber mounts were used to attach the electrical generator and engine to the gen set frame. This was done so that noise measurements can be taken at Fort Belvoir, at a later date, to determine the effect of the soft mounts.

TRANSIENT ELECTRICAL TESTS

Three transient tests were called-out in the contract. These are defined by mil. std. 705B, Generator Sets, Engine Driven, Methods of Test and Inspection:

- (1) Method 608.1a, Frequency and Voltage Regulation, Suitability and Transient Response Test (Short-Term).
- (2) Method 619.1c, Voltage Dip for Low Power Factor Load Test.
- (3) Method 619.2b, Voltage Dip and Rise for Rated Load Test.

All electrical tests were performed by Libby at their test facility in Kansas City, Mo. These test are routinely conducted by Libby as part of their day-to-day activity building a variety of DoD gen sets. Figure 11 is a copy of the data taken by Libby which show that the demonstrator, turbo-charged, DED gen set exceeded the criteria for compliance for the three designated tests. (See last two pages of figure 11). Figure 12 is a copy of a portion of the oscillograph record made by Libby as part of the method 608.1a test. The second page of figure 12 shows that the recovery time was 0.3 seconds and frequency change was 4.2 Hz when the load was instantaneously changed from 0 to 100%. When the load was changed from 100% to no-load, the frequency change was 2.6 Hz and the recovery time was 0.25 seconds.

Additional transient tests were conducted with the load instantaneously changing from zero to 40KW, 30% greater than the rated generator load. The performance specifications were again met.

After successful completion of the testing at Libby, both the demonstrator gen set and the D298ER engine removed from the GFE gen set were shipped to Fort Belvoir.

MFR LIBBY WELDING COMPANY, INC.

DATE: MAR 11 1961

SERIAL NO PZ 40334
RATING 30 KW, 400 HZ.

I. 5

CONTRACT CR ORDER

NO. DAAJ08-81-C-1764

OFFICIAL TEST RECORD

LIBBY WELDING CO.
2201 MANCHESTER
KANSAS CITY, MO. 64126

DESCRIPTION	STABILIZATION
1. The first step in stabilizing a patient is to ensure that the airway is open and that breathing is adequate.	
2. If the patient is unconscious or unable to breathe on their own, artificial ventilation should be initiated.	
3. Once the airway is secured, the next step is to check for and treat any life-threatening injuries.	
4. This includes checking for major bleeding, fractures, and signs of shock.	
5. If there are no immediate threats to life, the patient should be reassessed regularly.	
6. The goal is to stabilize the patient's condition enough to transport them safely to a hospital.	

GOVT INSP.

TEST NUMBER 9

REF ID: A60913

DATE 17 Aug 82

TESTED BY FRM. lkr

[illegible]

FIGURE 11 - (con't)

MFR LIBBY WELDING COMPANY, INC.

MODEL REP 014ASERIAL NO R2 40334RATING 30 KV, 400HZ.T. P

CONTRACT OR ORDER

NO. DAJ99-81-C-1764

OFFICIAL TEST RECORD

LIBBY WELDING CO.

2201 MANCHESTER
KANSAS CITY, MO. 64126

TEST NUMBER

METHOD NO. T6081DATE 18 Aug 52TESTED BY MM

GOVT INSP

DESCRIPTION REGULATOR AND GOVERNOR STABILITYAID TRANSIENT RESPONSE, 60/400 HZ, 1250F AMBIENT

INST. NO	READ NO.	Voltage			Line Current			Pwr.		Extr. Field		Bandwidth		Regulation		Freq		Surge		Load	
		L1-N	L2-N	L3-N	L1	L2	L3	Out	Freq.	Volt.	Curr.	Volt	Freq.	Volts	Freq.	O/S	%	O/U	%	From	To
		Volts	Volts	Volts	Amps	Amps	Amps	KW	HZ	Volts	Amps	%	%	%	%	%	%	%	%		
		x1	x1	x1	x1	x1	x1	x1	x1	x1	x1	x1									
					Rated Load (Start)																
	1	119.8	120.2	120.0	104.3	104.3	104.2	30.0	400.0	60.6	5.1	0	0.05	-	-	-	-	-	-	-	R/L
	2	119.0	120.1	120.2	0	0	0	0	400.0	61.3	3.8	0	0	0.08	0	0.65	-	-	0.25	R/L	N/L
	3	119.8	120.2	120.0	-	-	-	30.4	400.0	-	-	0	0.05	0.08	0	-	1.05	-	0.3	N/L	R/L
	4	120.0	120.2	120.2	-	-	-	0	400.0	-	-	0	0	0.08	0	0.6	-	-	0.25	R/L	N/L
	5	119.8	120.2	120.0	-	-	-	30.8	400.0	-	-	0	0.15	0.08	0	-	1.0	-	0.3	N/L	R/L
	6	120.1	120.2	120.2	-	-	-	0	400.0	-	-	0	0	0.08	0	0.6	-	-	0.25	R/L	N/L
	7	119.8	120.2	120.0	-	-	-	30.7	400.0	-	-	-	-	0.08	0	-	1.05	-	0.25	N/L	R/L
					3/4 Rated Load																
	8	119.7	120.2	120.1	78.3	78.4	78.1	22.3	400.0	60.8	4.9	0	0.05	-	-	-	-	-	-	-	3/4
	9	120.1	120.2	120.2	0	0	0	0	400.1	61.3	3.8	0	0.05	-	-	-	-	-	-	-	3/4 N/L
	10	119.8	120.2	120.1	-	-	-	22.4	400.1	-	-	0	0.05	-	-	-	-	-	-	-	N/L 3/4
	11	120.1	120.2	120.2	-	-	-	0	400.1	-	-	0	0.05	-	-	-	-	-	-	-	3/4 N/L
	12	119.8	120.2	120.1	-	-	-	22.4	400.1	-	-	0	0.05	-	-	-	-	-	-	-	N/L 3/4
	13	120.1	120.2	120.2	-	-	-	0	400.1	-	-	-	0.05	-	-	-	-	-	-	-	3/4 N/L
	14	119.8	120.2	120.1	-	-	-	22.4	400.1	-	-	-	-	-	-	-	-	-	-	-	N/L 3/4
REMARKS																					
		SHEET 46 OF 54																			

10/10/52
11/1/52
11/812.7
11.812.5
11.9

FIGURE 11 - (con't)

MFR LIBBY WELDING COMPANY, INC.

MODEL REP 114A

SERIAL NO RZ 40334

RATING 20 KW, 400 HZ.

T. 12

CONTRACT OR ORDER

NO. DAAJ09-81-C-1764

OFFICIAL TEST RECORD

LIBBY WELDING CO.

2201 MANCHESTER
KANSAS CITY, MO. 64126

DESCRIPTION REGULATOR AND COVERIOR STABILITY

AND TRANSIENT RESPONSE - 60/400 HZ.

TEST NUMBER

METHOD NO. T608 1

DATE 18 Aug 52

TESTED BY J. Miller

GOVT INSP

INST. NO	READ NO.	Voltage			Line Current			Pwr.		Freq. Hz	Extr. Field		Bardwidth		Regulation		Freq. Surge		Load	
		L1-N	L2-N	L3-N	L1	L2	L3	Out			Volt.	Curr.	Volt	Freq.	Volts	Freq.	O/S	U/S	From	To
UNITS		Volts	Volts	Volts	Amps	Amps	Amps	KW			Volts	Amps	%	%	%	%	%	%		
FACTOR		x1	x1	x1	x1	x1	x1	x1		x1	x1	x1								
15		119.9	120.2	120.1	52.2	52.1	52.3	15.2		400.1	61.1	4.4	0	0.05	-	-	-	-	2 1/4	RL
16		120.1	120.2	120.2	0	0	0	0		400.1	61.4	3.8	0	0.05	-	-	-	-	2 1/4	N/L
17		120.0	120.2	120.1	-	-	-	15.5		400.2	-	-	0	0.05	-	-	-	-	N/L	2 1/4
18		120.1	120.2	120.2	-	-	-	0		400.2	-	-	0	0.05	-	-	-	-	2 1/4	N/L
19		120.0	120.2	120.1	-	-	-	15.6		400.2	-	-	0	0.05	-	-	-	-	N/L	2 1/4
20		120.1	120.2	120.2	-	-	-	0		400.2	-	-	0	0.05	-	-	-	-	2 1/4	N/L
21		120.0	120.2	120.1	-	-	-	15.7		400.2	-	-	-	-	-	-	-	-	N/L	2 1/4
		1/4 Rated Load																		
22		120.0	120.3	120.2	26.1	26.0	26.0	2.5		400.2	61.2	4.0	0	0.05	-	-	-	-	1 1/4	RL
23		120.1	120.2	120.2	0	0	0	0		400.2	61.4	3.8	0	0.05	-	-	-	-	1 1/4	N/L
24		120.0	120.3	120.2	-	-	-	2.5		400.2	-	-	0	0.05	-	-	-	-	N/L	1 1/4
25		120.1	120.2	120.2	-	-	-	0		400.2	-	-	0	0.05	-	-	-	-	1 1/4	N/L
26		120.0	120.3	120.2	-	-	-	2.6		400.2	-	-	0	0.05	-	-	-	-	N/L	1 1/4
27		120.1	120.2	120.2	-	-	-	0		400.2	-	-	0	0.05	-	-	-	-	1 1/4	N/L
28		120.0	120.3	120.2	-	-	-	2.6		400.2	-	-	-	-	-	-	-	-	N/L	1 1/4
REMARKS																				

SHEET 47 OF 54

FIGURE 11 - (con't)

MFR LIBBY WELDING COMPANY, INC.MODEL HEP 1144SERIAL NO RZ 48334RATING 30 KW, 400 HZ.T.12

CONTRACT OR ORDER

NO. DRAJ09-81-C-1764

OFFICIAL TEST RECORD

LIBBY WELDING CO.

2201 MANCHESTER
KANSAS CITY, MO. 64126DESCRIPTION REGULATOR AND GOVERNOR STABILITYAND TRANSIENT RESPONSE, 60/400 HZ.TEST NUMBER 8METHOD NO. T608.1DATE 16 Aug 62TESTED BY THM

GOVT HISP

INST. NO	READ NO.	Voltage		Line Current			Powr.		Extr. Field		Bandwidth		Regulation		Surge		Load		
		L1-H	L2-H	L3-H	L1	L2	L3	Out	Freq.	Volts	Curr.	Volt	Freq	Volts	Freq	O/S	U/S	Change	
		Volts	Volts	Volts	Amps	Amps	Amps	KW	Hz	Volts	Amps	%	%	%	%	%	%	From	
		x1	x1	x1	x1	x1	x1	x1	x1	x1	x1							To	
		Rated Load (End)																	
	29	119.9	120.2	120.0	1038	1038	1038	30.0	400.2	60.7	50	0	0.1	-	-	-	-	R/L	
	30	120.1	120.2	120.2	0	0	0	0	400.2	61.4	3.8	0	0	0.08	0	0.6	-	0.25	R/L N/L
	31	119.8	120.2	120.0	-	-	-	30.3	400.2	-	-	0	0.1	0.08	0	-	1.0	0.25	N/L R/L
	32	120.1	120.2	120.2	-	-	-	0	400.2	-	-	0	0	0.08	0	0.6	-	0.25	R/L N/L
	33	119.8	120.2	120.0	-	-	-	30.3	400.2	-	-	0	0.1	0.08	0	-	1.05	0.25	N/L R/L
	34	120.1	120.2	120.2	-	-	-	0	400.2	-	-	0	0	0.08	0	0.6	-	0.25	R/L N/L
	35	119.8	120.2	120.0	-	-	-	30.4	400.2	-	-	-	-	0.08	0	-	1.0	0.25	N/L R/L
REMARKS																			

FIGURE 11 - (con't)

Model No. MFP-
 Serial No. E2
 Rating KW H2 T
 Contract No. 0AAJ09-81-C-1764

PRODUCTION TEST RESULTS

Libby Welding Company, Inc.
 2101 Manchester Trafficway
 Kansas City, Missouri 64126

Date _____

Test Engr. _____

Inspected _____

Test No.	Method Number	Method Title, Description of the Procurement Document Requirements, and Test Conditions	Procurement Requirement	Test Results	Compliance with Procurement Document
18	516.5	Reverse Polarity			
		Reverse Polarity Damage	None		
46	602.1	Voltage Modulation			
		% Modulation	1.0% Max.		
		Data Sheet & Photographs attached.			
47	T619.1c	Voltage Dip for Low Power Factor			
		(400 Hz, TP Sets)			
		Allowable voltage dip	75%		
		Recovery time	0.7 Sec. Max.		
		Data Sheet and Oscillograms attached.			
45b	T601.4	Voltage Waveform (Harmonic Analysis)			
		Harmonic % of fundamental	2% Max.		
		Notches, spikes, discontinuities in waveform	None		
		Data Sheet and photographs attached.			
56/13	T512.1	Circuit Interrupter-Short Circuit (125° F)			
		a. Indicator light	On		
		B. Circuit breaker	Open		
		Data Sheet and Oscillographs attached.			
56/14	T512.3c	Overvoltage and Undervoltage Trip (125° F)			
		I. Overvoltage, 156 for 200 msec	156 volts		
		a. trip time	1.25 sec.		
		b. indicator light	ON		
		c. engine	Shut down		
		II. Undervoltage (TP Only)			
		a. indicator light	ON		
		b. circuit breaker	Open		
		c. 47 volt trip, instant.	47V/instant.		
		d. 95 volt trip time delay	95V/6+ 2 sec.		

FIGURE 11 - (con't)

Model No. MEP-Serial No. RZRating KV HZ TContract No. DAAJ09-81-C-1764PRODUCTION TEST RESULTSLibby Welding Company, Inc.
2201 Manchester Trafficway
Kansas City, Missouri 64126Date 16/AUG/82Test Engr. F.M.Inspected G.F.

Test No.	Method Number	Method Title, Description of the Procurement Document Requirements, and Test Conditions	Procurement Requirement	Test Results	Compliance with Procurement Document
56/8	T608.1a	Short Term Frequency and Voltage Regulation, Stability and Transient Response, Tactical Precise 60/400 (125°F)			
		Max. frequency bandwidth	.5%	0.15%	OK
		Max. frequency recovery time	1.0 sec.	0.3 sec.	OK
		Max. frequency overshoot	1.5%	1.05%	OK
		Max. frequency regulation	.25%	0	OK
		Max. voltage bandwidth	1.0%	0	OK
		Max. voltage regulation	1.0%	0.08%	OK
		Data sheet and chart attached.			✓
56/13	T512.2c	Circuit Interrupter (Overload) (125°F)			
		a. trip time 130% overload min.	8 + 2		
		b. indicator light	ON		
		c. circuit breaker	Open		
		d. 110%-no trip	no trip		
		e. trip time for Phase A, 130% overload	8 + 2		
		f. trip time for Phase B, 130% overload	8 + 2		
		g. trip time for Phase C, 130% overload	8 + 2		
56/26	T511.1c	Regulator Range (125°F)			
		Min. voltage adjust L-N, 60 & 400 Hz	114		
		Max. voltage adjust L-N, 60 Hz	138.5		
		Max. voltage adjust L-N, 400 Hz	132		
		Min. voltage-mechanical stop 60 & 400 Hz Measure			
		Max. voltage-mechanical stop 60 & 400 Hz Measure			
56/28	T511.2b	Frequency Adjustment Range (TP Only) (125°F)			
		Max. frequency adjust, 60 Hz.	62 to 65		
		Max. frequency adjust, 400 Hz.	420 to 430		
		Min. frequency adjust, 60 Hz.	58		
		Min. frequency adjust, 400 Hz.	370 to 390		
		Min. frequency-mechanical stop	Measure		

FIGURE 11 - (con't)

Model No. MEP
Serial No. RZ
Rating EW HZ T
Contract No. DAAJ09-81-C-1764

PRODUCTION TEST RESULTS

Libby Welding Company, Inc.
2201 Manchester Trafficway
Kansas City, Missouri 64126

Date _____

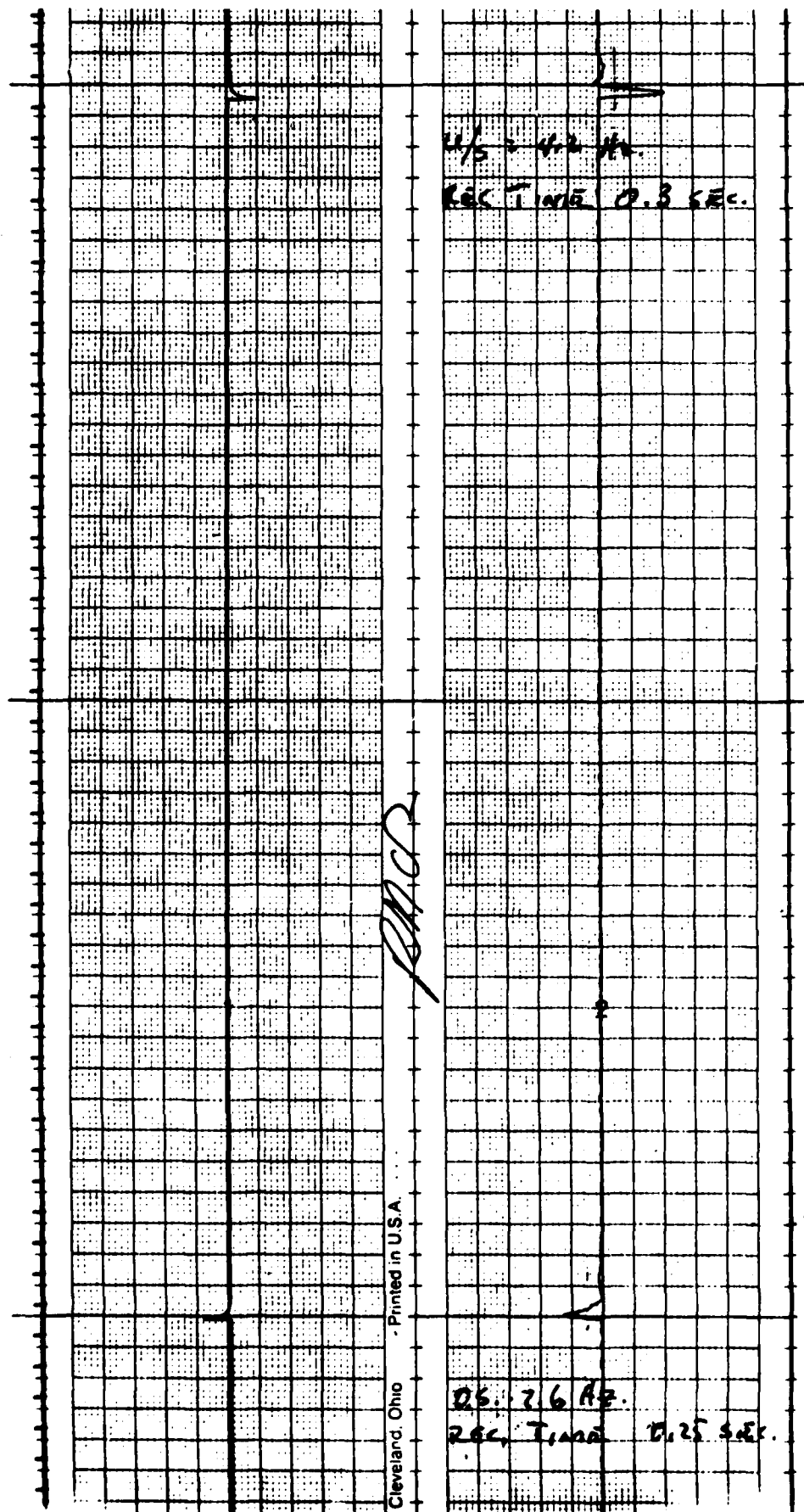
Test Engr. _____

Inspected _____

Test No.	Method Number	Method Title, Description of the Procurement Document Requirements, and Test Conditions	Procurement Requirement	Test Results	Compliance with Procurement Document
56/28	T511.2b	Frequency Adjustment Range (TP Only) (125°F) Cont.			
		Max. frequency-mechanical stop	Measure		
		Underfrequency device activated	Note		
56/67	T608.2	Long Term Frequency and Voltage Stability, (125°F), TP.			
		Maximum frequency bandwidth	1%		
		Maximum voltage bandwidth	2%		
		Transient Portion:			
		Max. frequency recovery time	1 sec.		
		Max. frequency overshoot	1.5%		
		Max. frequency undershoot	1.5%		
		Max. frequency regulation 0.25%			
		Data sheet and chart attached			
56/47	T619.1c	Voltage Dip for Low Power Factor. (125°F) - 400 HZ, TP			
		Allowable voltage dip	75% min.	79.4	—
		Recovery time	0.7 sec max.	.22	—
		Data sheet and oscillograms attached.		yes	✓
56/48	T619.2b	Voltage Dip and Rise (125°F) 400 Hz.TP			
		Voltage dip	88%	91	—
		Recovery time	0.5 sec max.	.14	—
		Voltage rise	112% max.	105.6	—
		Recovery time	0.5 sec. max.	.14	—
		Data sheet and oscillograms attached.		yes	✓

[illegible]

FIGURE 12 - (con't)



from no-load
to 100% load

from 100% load
to no-load

Cleveland, Ohio - Printed in U.S.A.

VII CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The major conclusion which can be drawn from the test results in section VI of this report is that a turbocharger with VATN (variable area turbine nozzle), and equipped with an appropriate VATN controller, eliminates the turbocharger lag problem which has, in the past, kept the turbocharged DED gen set from complying with mil. std. 705B. The second conclusion is based on analytical results in section II as improved from the engine testing discussed in section V. From these results it is estimated that the application of a down-sized, turbocharged diesel engine to the DED 30KW-400Hz gen set, currently powered by a naturally aspirated engine, can improve the fuel economy of the gen set by at least 9.0%. Also, the turbocharged gen set would be capable of delivering rated power up to an altitude of 8000 feet on a day with the temperature 60 F hotter than standard.

RECOMMENDATIONS

The engine math model was used to estimate the fuel savings which could be realized by applying a D 3400-T engine equipped with a VATN turbocharger to a 60KW-60Hz, DED gen set. The D 3400-T is the six cylinder version of the four cylinder D 2300-T. Table VII lists the results of the calculations. A constant intake manifold pressure of 12 psig was assumed. The indicated thermal efficiency multiplier deduced in section V was also used. Point numbers 49 through 53 are for sea level, standard day, operation over the load range. The calculated fuel consumption for one mil. std. 705B duty cycle is 370.2 gallons. This is 17.5% less than the 448.8 gallons required by the current gen set. It is also recommended that fuel consumption tests, hot day tests, and altitude test be performed on the demonstrator unit which resulted from this contract. This information will enable all the performance aspects of the turbocharged DED gen set, not investigated during this contract, to be assessed.

TABLE VII - Summary of Calculation Points Used to Estimate Fuel Savings for 60KW-60Hz DED Gen Set

CALC NO.	DISP In ³	NE RPM	ALT Ft.	P2/P1	A/F	FUEL FLOW Gal/Hr.	POWER BHP	LOAD FRACTION %	η WITH MULT
49	339	1800	0	1.816	28.8	5.258	98.1	100	.9678
50				1.816	35.8	4.221	76.4	75	
51				1.816	45.4	3.320	54.4	50	
52				1.816	62.3	2.407	30.9	25	
53				1.816	112.0	1.323	0	0	
54	339	2000	0	1.816	30.9	5.403	98.1	100	
55	339	1800	8000	2.099	23.4	5.579	98.1	100	
56	339	1800	8000 + 60 F	2.099	19.6	6.028	98.1	100	

APPENDIX

Computer output for calculation number 43, TABLE VI

***** 967824XEFITH*****

4 CYL DIESEL ENGINE CALCULATION
WITH 1 TURBOCHARGER

ID=00/17/00 22:45:18 , 22.1167

ENG SPEED	TORQUE	NET POWER	BMEP	FMEP	ENG DELP(I-E)	VOL EFF	I. THERM EFF
2000 RPM	128.66 FT-LB 174.47 N-M	49.00 HP 36.54 KW	85.85 PSIA 5.92 BAR	38.56 PSIA 2.11 BAR	1.60 PSIA 0.11 BAR	0.9245 (0.920, 0.924)	0.4485 (1.0000)

DISPLCMT	STROKE	COMPR RAT	AMB TEMP	AMB PRES	EQ RAT	TF	FMEP ADJ	QDOT
226.00 IN ³ 3.70 LITER	4.5000 IN 114.30 MM	16.0000	59.00 DEG F 15.13 DEG C	14.700 PSIA 1.0132 BAR	0.4645 -21.0502	-0.3550 0.3553	1.0000 18.5700	0.0000

COOL EFF	% BLOW BY	LEAK9-A	LEAK9-S	LEAK DTS	BSHC	BSCD	BSND	BOSCH
0.0000	0.0000	0.0000	0.0000	0.0000	1.0571	1.8396	5.9901	0.3683

VAP PHR	VAP MEP	T MIX	T COMPR	VAP DT	P COMPR	VAP DP	WR/MGS
-0.00 HP -0.00 KW	-0.00 PSI -0.00 BAR	626.85 DEG R 75.05 DEG C	1818.43 DEG R 737.04 DEG C	0.00 DEG R 0.00 DEG C	900.97 PSI 67.62 BAR	-0.00 PSI -0.00 BAR	0.0307

F#	TYPE	M/MTOT	ZVAP-MIX	VAP EF	BSFC-0/HH	BSFC-G/KH	LB/HR	CARB DP/P	AIR/FUEL
----	------	--------	----------	--------	-----------	-----------	-------	-----------	----------

3	DIESEL	1.0000	0.0000	1.0000	0.4296	261.33	21.05	0.0000	32.326
---	--------	--------	--------	--------	--------	--------	-------	--------	--------

2.879

OUTPUT BELOW THIS POINT IS PER TURBOCHARGER:

RC	COMP EF	NCC	MCC	QC	AREA IN	DT IN	DT EX	EFSF	DT HT
1.4378	0.7200 0.6349	69000 RPM	0.1890 LB/S 0.0004 KG/S	140.32 CFM 0.0700 M ³ /S	1.6696 SQIN 1077.16 SQMM	1.7030 IN 43.256 MM	2.6660 IN 67.716 MM	1.0000	10.5

RETS	TURB EF	NCT	MCT	U/V' VANE THRT	VANE HT	ROT TH A	EFSF PH2/PH1
1.3090 (1.3090)	0.8340 (0.8340)	44823 RPM (0.0000)	0.2261 LB/S 0.1057 KG/S	0.7463 0.2157 IN 5.4793 MM	0.2500 IN 6.3500 MM	1.6500 SQIN 1064.51 SQMM	1.0000 1.0003

	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	519.00	519.00	519.00	519.00	608.03	608.03	1272.49	1239.50	1229.06	1161.17
TEMP-DEG C	15.13	15.13	15.13	15.13	64.60	64.60	433.74	415.41	410.06	371.89

VAP DT-R	0.00	0.00	0.00
VAP DT-C	0.0000	0.0000	0.0000
VAP FRCTN OF FUEL # 3	0.0000	0.0000	0.0000

PRES-PSIA	14.700	14.700	14.700	14.700	21.135	21.135	64.689	19.507	19.507	14.893
PRES-BAR	1.0132	1.0132	1.0132	1.0132	1.4568	1.4568	4.4500	1.3446	1.3446	1.0265

FLOW-LB/S	0.1890	0.1890	0.1890	0.1890	0.1890	0.1890	0.1949	0.1949	0.1949	0.1949
WRT/D-LB/S	0.1890	0.1890	0.1890	0.1890	0.1423	0.1423	0.0693	0.2269	0.2261	0.2877
FLOW-KG/H	300.6500	300.6500	300.6500	300.6500	300.6500	300.6500	318.1900	318.1900	318.1900	318.1900

LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566
-----------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------

Computer output for calculation number 44, TABLE VI

***** 967824XEFITH*****

4 CYL DIESEL ENGINE CALCULATION
WITH 1 TURBOCHARGER

ID=00/17/00 23:11:48 , 17.2167

ENG SPEED	TORQUE	NET POWER	BMEP	FMEP	ENG DELP(I-E)	VOL EFF	I. THRM EFF
2000 RPM	100.38 FT-LB	38.19 HP	66.92 PSIA	29.89 PSIA	1.12 PSIA	0.9200	0.4466
	136.00 N-M	28.48 KW	4.61 BAR	2.06 BAR	0.00 BAR	(0.917, 0.920)	(1.0000)

DISPLCMT	STROKE	COMPR RAT	AMB TEMP	AMB PRES	EQ RAT	TF	FMEP ADJ	QDOT
226.00 IN ³	4.5000 IN	16.0000	59.00 DEG F	14.700 PSIA	0.3955	-0.3550	1.0000	0.0000
3.70 LITER	114.30 MM		15.130 DEG C	1.0132 BAR	-17.6157	0.3417	15.4120	

COOL EFF	% BLOW BY	LEAK9-A	LEAK9-S	LEAK DTS	BSHC	BSCO	BSNO	BOSCH
0.0000	0.0000	0.0000	0.0000	0.0000	1.6863	2.7166	5.2770	0.4059

VAP PWR	VAP MEP	T MIX	T COMPRN	VAP DT	P COMPRN	VAP DP	MR/MGS
0.00 HP	0.00 PSI	619.19 DEG R	1799.34 DEG R	0.00 DEG R	959.85 PSI	0.00 PSI	0.0337
0.00 KW	0.00 BAR	70.00 DEG C	726.43 DEG C	0.00 DEG C	66.16 BAR	0.00 BAR	

FB	TYPE	M/TOT	%VAP-MIX	VAP EF	BSFC-G/H	BSFC-G/KH	LB/HR CARB	DP/P	AIR/FUEL
3	DIESEL	1.0000	0.0000	1.0000	0.4612	200.55	17.62	0.0000	37.968

OUTPUT BELOW THIS POINT IS PER TURBOCHARGER:

RC	COMP EF	NCC	MCC	QC	AREA IN	DT IN	DT EX	EFSF	DT HT
1.4044	0.7200	67500 RPM	0.1858 LB/S	145.78 CFM	1.6696 SQIN	1.7030 IN	2.6660 IN	1.0000	9.3
	0.6390		0.0068 KG/S	0.0680 M ³ /S	1077.16 SQMM	43.256 MM	67.716 MM		

RETS	TURB EF	NCT	MCT	U/V VANE THRT	VANE HT	ROT TH A	EFSF PM2/PM1
1.3131	0.8353	45550 RPM	0.2127 LB/S	0.7553	0.2031 IN	0.2500 IN	1.0000 0.9990
(1.3131)	(0.8353)	(0.0000)	0.0994 KG/S	5.1585 MM	6.3500 MM	1064.51 SQMM	

	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	519.00	519.00	519.00	519.00	601.40	601.40	1175.54	1140.20	1139.70	1074.19
TEMP-DEG C	15.13	15.13	15.13	15.13	60.91	60.91	379.00	364.69	359.97	323.57

VAP DT-R			0.00		0.00	0.00				
VAP DT-C			0.0000		0.0000	0.0000				
VAP FRCTN OF FUEL # 3			0.0000		0.0000	0.0000				

PRES-PSIA	14.700	14.700	14.700	14.700	20.644	20.644	57.127	19.527	19.527	14.871
PRES-BAR	1.0132	1.0132	1.0132	1.0132	1.4229	1.4229	3.9376	1.3459	1.3459	1.0250

FLOW-LB/S	0.1858	0.1858	0.1858	0.1858	0.1858	0.1858	0.1907	0.1907	0.1907	0.1907
MRT/D-LB/S	0.1858	0.1858	0.1858	0.1858	0.1424	0.1424	0.0738	0.2135	0.2127	0.2712
FLOW-KG/H	303.3720	303.3720	303.3720	303.3720	303.3720	303.3720	311.3620	311.3620	311.3620	311.3620

LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566

Computer output for calculation number 45, TABLE VI

***** 967824XEFITH*****

4 CYL DIESEL ENGINE CALCULATION
WITH 1 TURBOCHARGER

ID=00/17/00 23:36:13 -1414.47

ENG SPEED	TORQUE	NET POWER	BMEP	FMEP	ENG DELP(I-E)	VOL EFF	I. THRM EFF
2000 RPM	71.42FT-LB	27.20 HP	47.65 PSIA	29.21 PSIA	0.59 PSIA	0.9146	0.4416
	96.04 N-M	20.28 KW	3.28 BAR	2.01 BAR	0.04 BAR	(0.913, 0.915)	(1.0000)

DISPLCMT	STROKE	CMR RAT	AMB TEMP	AMB PRES	EQ RAT	TF FMEP ADJ	QDOT
226.00 IN ³	4.5000 IN	16.0000	59.00 DEG F	14.700 PSIA	0.3257	-0.3550	0.0000
3.70LITER	114.30 MM		15.13 DEG C	1.0132 BAR	-14.1977	0.3222	12.2616

COOL EFF	% BLOW BY	LEAKS-A	LEAKS-S	LEAK DTS	BSHC	BSCO	BSNO	BOSCH
0.0000	0.0000	0.0000	0.0000	0.0000	2.6853	4.2773	4.9266	0.4855

VAP PWR	VAP MEP	T MIX	T COMPRN	VAP DT	P COMPRN	VAP DP	MR/MGS
0.00 HP	0.00 PSI	610.20 DEG R	1776.75 DEG R	0.00 DEG R	934.27 PSI	-0.00 PSI	0.0373
0.00 KW	0.00 BAR	65.00 DEG C	713.88 DEG C	0.00 DEG C	64.40 BAR	-0.00 BAR	

F0 TYPE	M/TOT	%VAP-MIX	VAP EF	BSFC-B/MH	BSFC-G/KH	LB/HR CARB DP/P	AIR/FUEL
3 DIESEL	1.0000	0.0000	1.0000	0.5220	317.54	14.20	0.0000 46.105

OUTPUT BELOW THIS POINT IS PER TURBOCHARGER:

RC	COMP EF	NCC	MCC	QC	AREA IN	DT IN	DT EX	EFSF	DT HT
1.3642	0.7200	65000 RPM	0.1810 LB/S	142.60 CFM	1.6696 SQIN	1.7030 IN	2.6660 IN	1.0000	0.0
	0.6430		0.0050 KG/S	0.0673 M ³ /S	1077.16 SQMM	43.256 MM	67.716 MM		

RETS	TURB EF	NCT	MCT	U/V	VAINE THRT	VAINE HT	ROT TH A	EFSF PM2/PM1
1.3107	0.8382	45761 RPM	0.1993 LB/S	0.7615	0.1910 IN	0.2500 IN	1.6500 SQIN	1.0000 1.0003
(1.3107)	(0.8382)	(0.0000)	0.0932 KG/S		4.8526 MM	6.3500 MM	1064.51 SQMM	

	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	519.00	519.00	519.00	519.00	593.60	593.60	1076.63	1054.53	1047.14	986.04
TEMP-DEG C	15.13	15.13	15.13	15.13	56.58	56.58	324.93	312.65	308.55	274.60

VAP DT-R		0.00		0.00	0.00
VAP DT-C		0.0000		0.0000	0.0000
VAP FRCTN OF FUEL	0.3	0.0000		0.0000	0.0000

PRES-PSIA	14.700	14.700	14.700	14.700	20.054	20.054	49.626	19.463	19.463	14.850
PRES-BAR	1.0132	1.0132	1.0132	1.0132	1.3823	1.3823	3.4206	1.3416	1.3416	1.0235

FLOW-LB/S	0.1810	0.1810	0.1810	0.1810	0.1810	0.1810	0.1850	0.1850	0.1850	0.1850
MRT/D-LB/S	0.1810	0.1810	0.1810	0.1810	0.1425	0.1425	0.0793	0.2000	0.1993	0.2535
FLOW-KG/H	296.9110	296.9110	296.9110	296.9110	296.9110	296.9110	303.3510	303.3510	303.3510	303.3510

LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566

Computer output for calculation number 46, TABLE VI

***** 967824XEFITH*****

4 CYL DIESEL ENGINE CALCULATION
WITH 1 TURBOCHARGER

ID=00/18/00 00:04:41 , 18.95

ENG SPEED	TORQUE	NET POWER	BMEP	FMEP	ENG DELP(I-E)	VOL EFF	I. THERMO EFF
2000 RPM	40.68FT-LB	15.46 HP	27.09 PSIA	28.48 PSIA	-0.11 PSIA	0.9100	0.4294
	55.05 N-M	11.53 KW	1.87 BAR	1.96 BAR	-0.01 BAR	(0.911, 0.911)	(1.0000)
DISPLCMNT	STROKE	COMPR RAT	AMB TEMP	AMB PRES	EQ RAT	TF FMEP ADJ	QDOT
226.00 IN ³	4.5000 IN	16.0000	59.00DEG F	14.700 PSIA	0.2460	-0.3550	0.0000
3.70LITER	114.30 MM		15.13DEG C	1.0132 BAR	-10.6604	0.2662	9.0079
COOL EFF	% BLOW BY	LEAK9-A	LEAK9-S	LEAK DTS	BSHC	BSCD	BSND
0.0000	0.0000	0.0000	0.0000	0.0000	5.0995	0.1841	5.5947
							BOSCH
							0.6172
VAP PMR	VAP MEP	T MIX	T COMPRN	VAP DT	P COMPRN	VAP DP	MR/MG5
-0.00 HP	-0.00 PSI	605.06 DEG R	1763.74 DEG R	0.00 DEG R	928.45 PSI	0.00 PSI	0.0427
-0.00 KM	-0.00 BAR	62.95 DEG C	706.66 DEG C	0.00 DEG C	64.00 BAR	0.00 BAR	

F#	TYPE	M/TOT	ZVAP-MIX	VAP EF	BSFC-0/HH	BSFC-G/KH	LB/HR CARB	DP/P	AIR/FUEL
3	DIESEL	1.0000	0.0000	1.0000	0.6896	419.45	10.66	0.0000	61.043

OUTPUT BELOW THIS POINT IS PER TURBOCHARGER:

RC	COMP EF	NCC	MCC	QC	AREA IN	DT IN	DT EX	EFSF	DT HT
1.3542	0.7200	63500 RPM	0.1800 LB/S	141.84 CFM	1.6696 SQIN	1.7030 IN	2.6660 IN	1.0000	6.3
	0.6560		0.0045 KG/S	0.0669 M ³ /S	1077.16 SQMM	43.256 MM	67.716 MM		
RETS	TURB EF	NCT	MCT	U/V' VANE THRT	VANE HT	ROT TH A	EFSF PM2/PM1		
1.3494	0.8236	46990 RPM	0.1823 LB/S	0.7440	0.1609 IN	0.2500 IN	1.6300 SQIN	1.0000	1.0001
(1.3494)(	0.8236)(	0.0000)	0.0852 KG/S		4.0876 MM	6.3500 MM	1064.51 SQMM		

	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	519.00	519.00	519.00	519.00	590.20	590.20	969.99	953.29	947.43	806.36
TEMP-DEG C	15.13	15.13	15.13	15.13	54.69	54.69	265.68	256.41	253.15	219.22
VAP DT-R			0.00		0.00	0.00				
VAP DT-C			0.0000		0.0000	0.0000				
VAP FRCTN OF FUEL # 3			0.0000		0.0000	0.0000				
PRES-PSIA	14.700	14.700	14.700	14.700	19.907	19.907	42.416	20.014	20.014	14.831
PRES-BAR	1.0132	1.0132	1.0132	1.0132	1.3721	1.3721	2.9236	1.3795	1.3795	1.0223
FLOW-LB/S	0.1800	0.1800	0.1800	0.1800	0.1800	0.1800	0.1837	0.1837	0.1837	0.1837
MRT/D-LB/S	0.1800	0.1800	0.1800	0.1800	0.1423	0.1423	0.0870	0.1829	0.1823	0.2300
FLOW-KG/H	295.1630	295.1630	295.1630	295.1630	295.1630	295.1630	299.9990	299.9990	299.9990	299.9990
LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566

Computer output for calculation 47, LABEL VI

***** 967824MEFITH*****

4 CYL DIESEL ENGINE CALCULATION
WITH 1 TURBOCHARGER

ID=00/18/00 00:25:45 , 56.6333

ENG SPEED	TORQUE	NET POWER	BMEP	FMEP	ENG DELP(I-E)	VOL EFF	I. THRM EFF
2000 RPM	-0.00FT-LB	-0.00 HP	-0.00 PSIA	27.54 PSIA	-1.30 PSIA	0.9062	0.3748
	-0.00 N-M	-0.00 KW	-0.00 BAR	1.90 BAR	-0.09 BAR	(0.910,0.906)	(1.0000)

DISPLNMT	STROKE	COMPR RAT	AMB TEMP	AMB PRES	EQ RAT	TF	FMEP ADJ	QDOT
226.00 IN ³	4.5000 IN	16.0000	59.00DEG F	14.700 PSIA	0.1462	-0.3550	1.0000	0.0000
3.70LITER	114.30 MM		15.13DEG C	1.0132 BAR	-6.3295	0.1862	4.5431	

COOL EFF	% BLOW BY	LEAK9-A	LEAK9-S	LEAK DTS	BSHC	BSCO	BSNO	BOSCH
0.0000	0.0000	0.0000	0.0000	0.0000%-360722	0000%-550073	0000%-229375	0000	0.9475

VAP PWR	VAP MEP	T MIX	T COMPRN	VAP DT	P COMPRN	VAP DP	WR/MGS
0.00 HP	0.00 PSI	600.51 DEG R	1752.17 DEG R	0.00 DEG R	929.35 PSI	0.00 PSI	0.0514
0.00 KW	0.00 BAR	60.42 DEG C	700.23 DEG C	0.00 DEG C	64.06 BAR	0.00 BAR	

F#	TYPE	M/MTOT	%VAP-MIX	VAP EF	BSFC-0/1H	BSFC-G/KH	LB/HP	CARB DP/P	AIR/FUEL
3	DIESEL	1.0000	0.0000	1.0000%-29638	4000%-18028400	00	6.33	0.0000	102.699

OUTPUT BELOW THIS POINT IS PER TURBOCHARGER:

RC	COMP EF	NCC	MCC	QC	AREA IN	DT IN	DT EX	EFSF	DT HT
1.3542	0.7200	63500 RPM	0.1005 LB/S	141.59 CFM	1.6696 SQIN	1.7030 IN	2.6660 IN	1.0000	4.4
	0.6742		0.0043 KG/S	0.0668 M ³ /S	1077.16 SQMM	43.256 MM	67.716 MM		

RETS	TURB EF	NCT	MCT	U/V' VANE THRT	VANE HT	ROT TH A	EFSF PM2/PM1
1.4310	0.7911	50010 RPM	0.1603 LB/S	0.7276	0.1263 IN	0.6500 SQIN	1.0000 1.0001
(1.4310)(	0.7911)(	0.0000)	0.0749 KG/S	3.2004 MM	6.3500 MM	1064.51 SQMM	

	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	519.00	519.00	519.00	519.00	508.18	508.18	851.98	840.62	836.51	773.77
TEMP-DEG C	15.13	15.13	15.13	15.13	53.57	53.57	200.12	193.01	191.53	156.67
VAP DT-R			0.00		0.00	0.00				
VAP DT-C			0.0000		0.0000	0.0000				
VAP FRCTN OF FUEL # 3			0.0000		0.0000	0.0000				
PRES-PSIA	14.700	14.700	14.700	14.700	19.907	19.907	24.811	21.209	21.209	14.813
PRES-BAR	1.0132	1.0132	1.0132	1.0132	1.3721	1.3721	2.1458	1.4619	1.4619	1.0210
FLOW-LB/S	0.1804	0.1804	0.1804	0.1804	0.1804	0.1804	0.1822	0.1822	0.1822	0.1822
MRT-D-LB/S	0.1805	0.1805	0.1805	0.1805	0.1419	0.1419	0.1008	0.1607	0.1603	0.2208
FLOW-KG/H	294.6560	294.6560	294.6560	294.6560	294.6560	294.6560	297.5250	297.5250	297.5250	297.5250
LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566

Computer output for calculation 48, TABLE VI

***** 967824XEFITH*****

4 CYL DIESEL ENGINE CALCULATION,
WITH 1 TURBOCHARGER

ID=00/20/00 21:28:42 , 63.15

ENG SPEED	TORQUE	NET POWER	BMEP	FMEP	ENG DELP(I-E)	VOL EFF	I. THERMO EFF
2000 RPM	128.92 FT-LB	49.09 HP	86.02 PSIA	30.54 PSIA	2.23 PSIA	0.9564	0.4129
	174.81 N-M	36.61 KW	5.93 BAR	2.11 BAR	0.15 BAR	(0.948, 0.956)	(1.0000)

DISPLCMNT	STROKE	COMPR RAT	AMB TEMP	AMB PRES	EQ RAT	TF	FMEP ADJ	QDOT
226.00 INE3	4.5000 IN	16.0000	90.10 DEG F	10.916 PSIA	0.6578	-0.3550	1.0000	0.0000
3.70 LITER	114.30 MM		32.41 DEG C	0.7524 BAR	-22.7654	0.3781	22.8976	

COOL EFF	% BLOW BY	LEAK9-A	LEAK9-S	LEAK DTS	BSHC	BSCD	BSNO	BOSCH
0.0000	0.0000	0.0000	0.0000	0.0000	0.4046	0.7666	12.9132	1.6624

VAP PMR	VAP MEP	T MIX	T COMPRN	VAP DT	P COMPRN	VAP DP	MR/MGS
0.00 HP	0.00 PSI	696.63 DEG R	1906.98 DEG R	0.00 DEG R	791.84 PSI	0.00 PSI	0.0263
0.00 KW	0.00 BAR	113.81 DEG C	830.68 DEG C	0.00 DEG C	54.58 BAR	0.00 BAR	

FI	TYPE	M/NTOT	%VAP-MIX	VAP EF	BSFC-B/MH	BSFC-G/KH	LB/MR	CARB DP/P	AIR/FUEL
3	DIESEL	1.0000	0.0000	1.0000	0.4637	282.07	22.77	0.0000	22.826

OUTPUT BELOW THIS POINT IS PER TURBOCHARGER:

RC	COMP EF	NCC	MCC	QC	AREA IN	DT IN	DT EX	EFSE	DT HT
1.5895	0.7200	76500 RPM	0.2001 LB/S	157.03 CFM	1.6696 SQIN	1.7030 IN	2.6660 IN	1.0000	17.1
	0.6223		0.0935 KG/S	0.0741 M3/S	1077.16 SQMM	43.256 MM	67.716 MM		

RETS	TURB EF	NCT	MCT	U/V' VANE THRT	VANE HT	ROT TH A	EFSE PM2/PM1
1.3625	0.8396	47126 RPM	0.2448 LB/S	0.7340	0.2162 IN	0.2500 IN	1.6500 SQIN
(1.3625)	(0.8396)	(0.0000)	0.1144 KG/S		5.4924 MM	6.3500 MM	1064.51 SQMM

	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	550.10	550.10	550.10	550.10	676.43	676.43	1526.47	1465.14	1449.57	1368.89
TEMP-DEG C	32.41	32.41	32.41	32.41	102.59	102.59	574.84	540.77	532.12	482.85
VAP DT-R			0.00		0.00	0.00				
VAP DT-C			0.0000		0.0000	0.0000				
VAP FRCTN OF FUEL # 3			0.0000		0.0000	0.0000				
PRES-PSIA	10.916	10.916	10.916	10.916	17.351	17.351	63.436	15.121	15.121	11.098
PRES-BAR	0.7524	0.7524	0.7524	0.7524	1.1960	1.1960	4.3725	1.0422	1.0422	0.7649
FLOW-LB/S	0.1443	0.1443	0.1443	0.1443	0.1443	0.1443	0.1507	0.1507	0.1507	0.1507
MRT/D-LB/S	0.2001	0.2001	0.2001	0.2001	0.1396	0.1396	0.0599	0.2461	0.2448	0.3232
FLOW-KG/H	235.6990	235.6990	235.6990	235.6990	235.6990	235.6990	246.0250	246.0250	246.0250	246.0250
LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566