

TECHNICAL REPORT

HEAVY-DUTY ENGINE TESTING REPORT
CUMMINS/EPA/TAIWAN CORRELATION
TEST RESULTS - 1993

by

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August, 1993

NOTICE

Technical Reports do not necessarily represent final EPA decisions or positions. They are intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position, or regulatory action.

Technology Evaluation and Testing Support Branch
Regulation Development and Support Division
Office of Mobile Sources
Office of Air and Radiation
U.S. Environmental Protection Agency

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1. Introduction/Background

The Taiwanese Government is in the process of adopting US mobile source emission regulations. As part of their program, they have been developing the appropriate heavy-duty engine emission testing capabilities, with aid from Cummins Engine Company and the Environmental Protection Agency (EPA). It is important for them to evaluate their lab and procedures by participating in a round robin program. A Cummins diesel engine was tested at Cummins Engine Company, Inc., EPA National Vehicle and Fuel Emissions Laboratory (NVFEL), and will be tested at the Taiwanese government laboratory. This report summarizes the emission results produced from the testing of a Cummins "6C" engine at the EPA NVFEL and Cummins' lab.

2. Engine, Fuel, Test Procedure and Test Plan

The characteristics of the engine used in this program are given below.

<u>Characteristic</u>	<u>Description</u>
1. Engine Manufacturer	Cummins
2. Engine Family	D41
3. Engine Type	6C-250
4. Displacement	504 in ³
5. Serial Number	44803148

<u>Characteristic</u>	<u>Value Measured at Cummins' Lab</u>
6. Idle Speed	681 rpm
7. Max. Power	252 Hp
8. Max. Torque	800 ft-lb
9. Rated Speed	2200 rpm
10. Peak Torque Speed	1300 rpm
11. Fuel Consump. at Max. Power	96.7 lb/hr
12. Fuel Consump. at Max. Torque	65.2 lb/hr
13. Inlet Depression	20.1 in H ₂ O
14. Exhaust Backpressure	2.3 in Hg
15. Water In @ Rated Speed	167° F
16. Water Out @ Rated Speed	185° F
17. Oil @ Rated Speed	224° F
18. Fuel Temp. @ Rated Speed	104° F
19. Intercooler Air In	250 - 300° F
20. Intercooler Air Out	114° F
21. Exhaust Temp. @ Rated Speed	957° F

The D-2 diesel fuel used for all testing was provided by Cummins. The characteristics of this fuel were provided by Cummins in their diesel fuel oil inspection report, a copy of which is included in the Appendix. Pertinent fuel properties are given in Table 1.

Table 1
Diesel Fuel Analysis and CFR Specifications

Item	CFR Specifications ^a		Cummins Petroleum Analysis
	ASTM	Type D-2	
Cetane Number	D613	42-50	45.7
Distillation Range:			
IBP °F	D86	340-400	348
10% Point, °F	D86	400-460	407
50% Point, °F	D86	470-540	495
90% Point, °F	D86	550-610	594
EP, °F	D86	580-660	642
Gravity, API	D287	33-37	34.4
Total Sulfur, %	D129 or D2622	0.20-0.50	0.31
Hydrocarbon Composition:			
Aromatics, %	D1319	27 ^b	31.2
Paraffins, Naphthenes, Olefins	D1319	c	68.8
Flashpoint, °F (min.)	D93	130	140
Viscosity, Centistokes	D445	2.0-3.2	2.36
^a Diesel fuel specification as in CFR 86.1313-90(b) (2) for 1990 on-road heavy-duty diesel engines. ^b Minimum ^c Remainder			

The fuel was introduced to the engine by transferring it from the barrel in which it was shipped to the normal laboratory fuel delivery system by an auxiliary lift pump. It was presented to the engine at a pressure of 0 to 0.5 psi and a temperature less than 100° F.

The scope of work for this program is as follows (a copy of the test plan is included in the Appendix):

1. Set specifications at rated speed = 2200 rpm

Intake restrictions: 18.5 ± 1 in H₂O at rated speed
Exhaust restrictions: $2.4 \pm .2$ in Hg at rated speed

Intake manifold temp $115 \pm 3^{\circ}$ F
Process water to CAC $77 \pm 4^{\circ}$ F
Delta P across CAC < 3 in Hg

Note: CAC = Charge Air Cooler.

2. Run steady state performance
Run 3 lines of data at 1300, 2000, and 2200 rpm
Rated - 2200 rpm and Torque Peak - 1300 rpm
3. Run a torque curve and throttle sweeps
Accessory idle loading (CITT) = "0" ft-lbs
4. Run 3 conditioning cycles - Measure particulates.
5. Overnight soak to 86° F.
6. Perform a cold cycle - followed by a 20 minute soak.
7. Perform 6 hot cycles with 5 minute soaks between. Oven extract the particulate filters from the cold and hot starts.

3. Testing/Results

The engine was set up in EPA/NVFEL test cell #1 and the steady state performance was evaluated to assure that the engine was running correctly. The recorded torques and fuel flows at 1300, 2000 and 2200 rpm were compared to Cummins' set-up data (see Table 2). The data were found to be similar and thus EPA judged the engine was operating properly.

Next, a torque-map was performed on the engine, followed by three conditioning cycles. Then, after an overnight soak, a cold-start and six hot-starts were performed.

Table 3 presents the EPA data from testing the Cummins 6C correlation engine using the fuel provided by Cummins. A copy of the individual emissions test summary sheets are included in the Appendix.

Table 2
EPA and Cummins Steady State Performance Data

SPEED, RPM	TORQUE, FT-LB			FUEL FLOW, LB/HR		
	1300	2000	2200	1300	2000	2200
EPA	808.0	664.0	606.5	66.2	91.8	98.2
CUMMINS	800.0	656.5	601.0	65.2	-----	96.7

Table 3
EPA HD-FTP Test Results

	Emissions				BSFC	Actual Work
	g/BHp-hr					
	HC	CO	NO _x	PM (CF) ¹	lb/BHp-hr	BHp-hr
PREP 1 ²	----	----	----	0.146	----	16.624
PREP 2 ²	----	----	----	0.166	----	16.712
PREP 3 ²	----	----	----	0.176	----	16.622
CS	0.616	1.403	4.666	0.210 (0.139)	0.391	16.749
HS 1	0.557	0.994	4.461	0.183 (0.130)	0.379	16.740
HS 2	0.583	0.985	4.600	0.187 (0.133)	0.378	16.606
HS 3	0.584	0.948	4.502	0.185 (0.128)	0.375	16.707
HS 4	0.580	0.964	4.417	0.187 (0.128)	0.377	16.679
HS 5	0.561	0.948	4.430	0.185 (0.130)	0.373	16.694
HS 6 ³	----	----	----	---- (----)	----	----
Hot Start Statistics						
AVG.	0.573	0.968	4.482	0.185 (0.130)	0.376	16.685
2 STD DEV.	0.026	0.042	0.147	0.003 (0.004)	0.005	0.099
C.O.V. ⁴	4.52%	4.36%	3.29%	1.81% (3.16%)	1.28%	0.60%
COMP. ⁵	0.567	1.061	4.494	0.187 (0.131)	0.381	16.741

¹CF = Carbonaceous Fraction, Based on Oven Extraction, in g/BHp-hr.

²Preparatory Run.

³This test failed cycle statistic requirements for reasons that were not determined.

⁴C.O.V. = Coefficient of Variation, computed by (2 STD DEV. / AVG.).

⁵COMP. = Composite value calculated from CS and the HS (HS 1) that immediately followed the CS.

4. Comparison of EPA and Cummins Data

Table 4 presents data which compares EPA's results with those produced by the Cummins lab (a copy of Cummins detailed data is in the Appendix).

Table 4
Comparison of EPA and Cummins Test Results

LAB	RESULTS					
	HC	CO	NO _x	PM (CF) ¹	BSFC	ACTUAL WORK
	g/BHp-hr				lb/BHp-hr	BHp-hr
Prep. Average Result Comparison						
EPA	----	----	----	0.163	----	16.653
CUMMINS	----	----	----	0.193	----	17.49
% Difference ²	----	----	----	18.4%	----	5.0%
Cold Start Result Comparison						
EPA	0.616	1.403	4.666	0.210 (0.139)	0.391	16.749
CUMMINS	0.531	1.170	4.758	0.212	0.4103	17.39
% Difference ²	-13.8%	-16.6%	2.0%	1.0%	4.9%	3.8%
Hot Start Average Result Comparison						
EPA	0.573	0.968	4.482	0.185 (0.130)	0.376	16.685
CUMMINS	0.528	0.926	4.623	0.187	0.3992	17.46
% Difference ²	-7.9%	-4.3%	3.1%	1.1%	6.2%	4.6%
Composite Result Comparison ³						
EPA	0.567	1.061	4.494	0.187 (0.131)	0.381	16.741
CUMMINS	0.534	0.888	4.653	0.189	0.3992	17.49
% Difference ²	-5.8%	-16.3%	3.5%	1.1%	4.8%	4.5%

¹CF = Carbonaceous Fraction, Based on Oven Extraction, in g/BHp-hr.

²The % Difference is computed relative to EPA data.

³Composite value calculated from CS and the HS that immediately followed the CS.

5. Analysis and Conclusions

Prior to the emission testing of this engine at the EPA NVFEL, similar testing (using the same engine) was done at Cummins. A comparison of the composite test results from both laboratories is presented below.

Comparison of Composite HD-FTP Emission Levels Between Laboratories

		<u>EPA Level</u>	<u>Cummins Level</u>	<u>% Difference</u>
HC	(g/BHp-hr)	0.567	0.534	-5.8
CO	(g/BHp-hr)	1.061	0.888	-16.3
NO _x	(g/BHp-hr)	4.494	4.653	3.5
PM	(g/BHp-hr)	0.187	0.189	1.1
BSFC	(g/BHp-hr)	0.381	0.3992	4.8
Act.Work	(BHp-hr)	16.741	17.49	4.5

The percent difference in the HC, NO_x and PM data between the two facilities is generally in the range observed in other, similar, round robin programs. The difference in CO data between facilities is larger than normally observed and was not investigated in this program.

Appendix

Cummins Diesel Fuel Oil
 Inspection Report
Test Plan
Individual Emissions
 Test Summary Sheets
Cummins Data

DIESEL FUEL OIL INSPECTION
REQUISITION AND REPORTSample No. 43501Prog./Proj. No. 20500Requestor's Identification CINAY FEUCHTDept. No. 8521Requested: Date 2/2/93 By _____Mail
Code 50180Phone 4183Type: ☐ 1-D ☐ 2-D ☐ 4-D ☐ _____ Supplier _____

Location: _____

Date Sample Taken: 2/2/93 From: ☐ MSL ☐ Truck ☐ _____ Rep. of _____ GalPurpose of Tests: APTC - TAIWAN QC CORRELATIONDate Sample Received: 2-3-93 ☐ Retain ☐ Return ☐ Discard

Reported By _____ To _____ Date _____

7.1168 16/gallon

METHOD OF INSPECTION IS ASTM UNLESS OTHERWISE NOTED.

<input checked="" type="checkbox"/> Gravity, 60°F (D-287)	34.4 (34.7 ALI) °API	<input checked="" type="checkbox"/> Distillation (D-88)	REMARKS: ALI results
<input checked="" type="checkbox"/> Specific Gravity 60/60 °F	.853 g/ml	Bar. in Hg	
<input checked="" type="checkbox"/> Viscosity, Kinematic (D-445)	2.36 (2.39 ALI) CST @ 100°F	% Evap'd. Temp.	
<input type="checkbox"/> Pour Point (D-97)	°F	Initial 348 °F	341.0
<input type="checkbox"/> Cloud Point (D-2500)	°F	5 °F	387.0
<input checked="" type="checkbox"/> Flash Point (D-93)	140 (ALI results) °F	10 407 °F	408.0
<input type="checkbox"/> Potential Gum (D-873)	mg/100 ml	15 °F	
<input type="checkbox"/> Stream Jet Gum (D-381)	mg/100 ml	20 433 °F	434.0
<input type="checkbox"/> Aniline Point (D-611)	°F	30 455 °F	456.0
<input type="checkbox"/> Corrosion, 212 °F (D-130)		40 °F	478.0
<input checked="" type="checkbox"/> Total Sulfur (D-1552)	.31 (.29 ALI) % wt.	50 495 °F	498.0
<input type="checkbox"/> FIA Hydrocarbon Type (D-1319)		60 °F	519.0
Saturates	68.4 % vol.	70 538 °F	540.0
Aromatics	31.2 % vol.	80 563 °F	564.0
Olefins	0.4 % vol.	85 °F	
<input type="checkbox"/> Ramsbottom Carbon (D-524)	On 10% Residuum	90 544 °F	593.0
<input type="checkbox"/> Ash (D-482)	On 10% Residuum	95 °F	618.0
<input checked="" type="checkbox"/> Cetane Number	45.7 % wt.	Final 642 °F	641.0
<input type="checkbox"/> Water and Sediment (D-1796)	% vol.	Recovery %	98.0
<input checked="" type="checkbox"/> Cetane Index (D-976)	44.1	Residue %	2.0
<input type="checkbox"/> Heat of Combustion (Estimated):		Loss %	0.0
Net	Btu/lb.		
Gross	Btu/lb.		

REMARKS: Mailed to ALI 2-3-93



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

ANN ARBOR, MICHIGAN 48105

OFFICE OF
AIR AND RADIATION

MEMORANDUM

SUBJECT: Test Plan - Taiwan Round Robin - 1993

FROM: Mark H. Doorlag, Project Engineer
Technology Evaluation and Testing Support Branch

THRU: Thomas M. Baines, Senior Technical Advisor
Technology Evaluation and Testing Support Branch

TO: John F. Anderson, Chief
Technology Evaluation and Testing Support Branch

1. INTRODUCTION:

The Taiwanese Government is in the process of adopting US mobile source regulations. In turn, they have been developing the appropriate emission testing capabilities, with aid from Cummins Engine Company and EPA. It is important for them to evaluate their lab and procedures by participating in a round robin program. A Cummins diesel engine will be tested at Cummins Engine Company, Inc., Southwest Research Institute, EPA NVFEL, and at the Taiwanese government laboratory. This test plan is for the testing of this engine at the NVFEL.

2. OBJECTIVE:

Develop a data base on an engine that will permit the Taiwanese Government to evaluate how well their laboratory correlates with the EPA-NVFEL.

3. PROJECT SCOPE OF WORK:

Engine Information

6C CORRELATION ENGINE (ARTC)
Engine Family - D41
ESN - 44803148
CPL - 1262
Cylinders - 6
Displacement - 504 in³
Rated Speed - 2200 RPM

Procedure

1. Setup the computer files for database information and accessory load as provided. Please make sure target torque is databased.
2. Use 0.1% sulfur fuel (barrels supplied).
3. Set specifications at rated speed = 2200 rpm

Intake restrictions: 18.5 ± 1 in H₂O (emissions) rated
Exhaust restrictions: $2.4 \pm .2$ in Hg (emissions) rated

Intake manifold temp 115 ± 3 °f at command
Process water to CAC 77 ± 4 °f at command
Delta P across CAC < 3 in Hg at command
4. Run steady state performance
Run 3 lines of data at 1300, 2000, and 2200 rpm
Rated - 2200 and Torque Peak - 1300

Expected Performance: 250 Hp at 2200 & 2000 rpm
800 ft-lb at 1300 rpm
5. Run a torque curve and throttle sweeps

Accessory idle loading (CITT) = "0" ft-lbs
6. Run 3 conditioning cycles - Measure particulates.
No extractions.
(Set PBS to .17% and SDS to .06%).
7. Overnight soak to 86 °F.
8. Perform a cold cycle - followed by a 20 minute soak.
9. Perform 6 hot cycles with 5 minute soaks between.
Solvent extract the cold, 1st, 3rd, and 4th hot only,
(SFE) oven extract all others.
10. Reset the restrictions at 2200 rpm for smoke cycle.
Intake air restriction 25 ± 1 in H₂O (smoke)
Exhaust restriction $3.0 \pm .2$ in H₂O (smoke)
11. Run federal smoke test.

Additional Information

CVS flow rate is 2200 scfm.

PBS (sample flow) = 0.17% CVS
= 2200 scfm x .17/100 = 3.74 scfm

SDS (secondary dilution flow) = 0.06% CVS
= 2200 scfm * .06/100
= 1.32 scfm

DR (dilution ratio) = (sample + secondary dilution flow) / sample

$$= \frac{\left(2200 \times \frac{.17}{100}\right) + \left(2200 \times \frac{.06}{100}\right)}{\left(2200 \times \frac{.17}{100}\right)}$$

$$= \frac{.23}{.17}$$

$$= 1.35$$

4. OUTPUT:

A brief report summarizing the test results.

5. TIMING:

This project should start on Tuesday, February 16, 1993 and be completed by Friday, March 5, 1993.

6. LEVEL OF EFFORT:

	<u>Hours</u>
Engineer	20
Technician	120

7. BUDGET ESTIMATE:

Not applicable.

8. SAFETY INFORMATION:

See attached form.

9. MILESTONES:

See attached form.

10. RECOMMENDED PRIORITY:

Low

11. ADDITIONAL COMMENT:

None

12. Review/Approval:

Review:

Lee Jones _____ Date _____

Reviewed with the technician(s) _____

Approval:

John F. Anderson _____ Date _____

Priority _____

cc: C. Gray
L. Jones

Attachment

HD930093
999 D41ROUNDROBINT93 0
1B CS2E

HEAVY DUTY DIESEL TRANSIENT TEST

DATE: 04/08/93 TIME: 07:56:06 6

DIESEL SUMMARY REPORT

Test Number: HD930093 Manufacturer: EXPERIMENTAL
Test Date/Time: 4/ 7/93 8:29 Engine ID: 999 D41ROUNDROBINT93 0

AMBIENT DATA:

Barometer: 29.23 *HG
Dry Bulb Temperature: 77.50 F
Absolute Humidity: 60.22 Grains H2O/Lbs Dry Air

EMISSION RESULTS:

CS

HC (INTEGRATED):

Background, PPM 4.71
Exhaust+Bkg, Gms 13.06
Net, Gm/Bhp-Hr .616

CO (BAG):

Background, PPM 2.84
Exhaust+Bkg, Gms 26.80
Net, Gms/Bhp-Hr 1.40

NOX (INTEGRATED):

Background, PPM 1.52
Exhaust+Bkg, Gms 84.08
Net, Gms/Bhp-Hr 4.666

CO2 (BAG):

Background, PPM .043
Exhaust+Bkg, Gms 10148.41
Net, Gms/Bhp-Hr 558.7

PARTICULATE:

Secondary Tare, Gms .148723
Secondary Part, Gms .148884
Primary Tare, Gms .149387
Primary Part, Gms .153440
Total, Gms/Bhp-Hr .21

FUEL CONSUMPTION:

Lbs/Carbon Balance 6.546
Lbs/Bhp-Hr .391
Lbs/Measured 6.892

BRAKE HORSEPOWER-HOUR: 16.749

CYCLE STATISTICS:

CS

SPEED:

Number 259
Slope .99542
(Limit: 0.97-1.03)
Y-Intercept 8.617
(Limit: +-50 RPM)
Std Error 18.138
(Limit: 100 RPM)
R-Square .99917
(Limit: 0.97)

TORQUE:

Number 297
Slope .96225
(Limit: 0.77/0.83-1.03)
Y-Intercept -6.904
(Limit: +-15 Ft-Lbs)
Std Error 7.927%
(Limit: 13% Max Eng Tq)
R-Square .91230
(Limit: 0.85/0.88)

POWER:

Number 259
Slope .98588
(Limit: 0.87/0.89-1.03)
Y-Intercept -2.512
(Limit: +-5 BHP)
Std Error 7.534%
(Limit: 8%)
R-Square .94317
(Limit: 0.91)

WORK:

Actual 16.749
(Limit: -15%-5% Ref Bhp-Hr)
Reference 17.579
% Difference -4.72%

HD930094
999 D41ROUNDROBINT93 0
1B HS7E

HEAVY DUTY DIESEL TRANSIENT TEST

DATE: 04/08/93 TIME: 07:58:20 6

DIESEL SUMMARY REPORT

Test Number: HD930094 Manufacturer: EXPERIMENTAL
Test Date/Time: 4/ 7/93 9: 9 Engine ID: 999 D41ROUNDROBINT93 0

AMBIENT DATA:

Barometer: 29.23 "HG
Dry Bulb Temperature: 77.50 F
Absolute Humidity: 60.44 Grains H2O/Lbs Dry Air

EMISSION RESULTS:

HS

HC (INTEGRATED):

Background, PPM 4.71
Exhaust+Bkg, Gms 12.06
Net, Gm/Bhp-Hr .557

CO (BAG):

Background, PPM 1.75
Exhaust+Bkg, Gms 18.67
Net, Gms/Bhp-Hr .99

NOX (INTEGRATED):

Background, PPM 1.52
Exhaust+Bkg, Gms 80.43
Net, Gms/Bhp-Hr 4.461

CO2 (BAG)

Background, PPM .038
Exhaust+Bkg, Gms 9778.66
Net, Gms/Bhp-Hr 542.5

PARTICULATE:

Secondary Tare, Gms .146997
Secondary Part, Gms .147109
Primary Tare, Gms .147953
Primary Part, Gms .151496
Total, Gms/Bhp-Hr .18

FUEL CONSUMPTION:

Lbs/Carbon Balance 6.344
Lbs/Bhp-Hr .379
Lbs/Measured 6.679

BRAKE HORSEPOWER-HOUR:

16.740

CYCLE STATISTICS:

HS

SPEED:

Number 256
Slope .99381
(Limit: 0.97-1.03)
Y-Intercept 9.474
(Limit: +-50 RPM)
Std Error 17.578
(Limit: 100 RPM)
R-Square .99922
(Limit: 0.97)

TORQUE:

Number 297
Slope .96495
(Limit: 0.77/0.83-1.03)
Y-Intercept -7.930
(Limit: +-15 Ft-Lbs)
Std Error 7.643%
(Limit: 13% Max Eng Tq)
R-Square .91872
(Limit: 0.85/0.88)

POWER:

Number 256
Slope .98493
(Limit: 0.87/0.89-1.03)
Y-Intercept -2.833
(Limit: +-5 BHP)
Std Error 7.330%
(Limit: 8%)
R-Square .94589
(Limit: 0.91)

WORK:

Actual 16.740
(Limit: -15%-5% Ref Bhp-Hr)
Reference 17.579
% Difference -4.77%

HD930095
999 D41ROUNDROBINT93 0
1B HS8E

HEAVY DUTY DIESEL TRANSIENT TEST
DIESEL SUMMARY REPORT

DATE: 04/08/93 TIME: 08:00:47 6

Test Number: HD930095 Manufacturer: EXPERIMENTAL
Test Date/Time: 4/ 7/93 9:39 Engine ID: 999 D41ROUNDROBINT93 0

AMBIENT DATA:

Barometer: 29.22 "HG
Dry Bulb Temperature: 77.50 F
Absolute Humidity: 63.70 Grains H2O/Lbs Dry Air

EMISSION RESULTS:

HS

HC (INTEGRATED):

Background, PPM 4.57
Exhaust+Bkg, Gms 12.33
Net, Gm/Bhp-Hr .583

CO (BAG):

Background, PPM 1.31
Exhaust+Bkg, Gms 17.88
Net, Gms/Bhp-Hr .98

NOX (INTEGRATED):

Background, PPM 1.01
Exhaust+Bkg, Gms 80.59
Net, Gms/Bhp-Hr 4.600

CO2 (BAG)

Background, PPM .034
Exhaust+Bkg, Gms 9615.29
Net, Gms/Bhp-Hr 541.5

PARTICULATE:

Secondary Tare, Gms .147825
Secondary Part, Gms .147958
Primary Tare, Gms .147410
Primary Part, Gms .151002
Total, Gms/Bhp-Hr .19

FUEL CONSUMPTION:

Lbs/Carbon Balance 6.283
Lbs/Bhp-Hr .378
Lbs/Measured 6.679

BRAKE HORSEPOWER-HOUR: 16.606

CYCLE STATISTICS:

HS

SPEED:

Number 253
Slope .99230
(Limit: 0.97-1.03)
Y-Intercept 10.465
(Limit: +-50 RPM)
Std Error 20.322
(Limit: 100 RPM)
R-Square .99895
(Limit: 0.97)

TORQUE:

Number 297
Slope .96219
(Limit: 0.77/0.83-1.03)
Y-Intercept -9.137
(Limit: +-15 Ft-Lbs)
Std Error 7.649
(Limit: 13% Max Eng Tq)
R-Square .91729
(Limit: 0.85/0.88)

POWER:

Number 253
Slope .98077
(Limit: 0.87/0.89-1.03)
Y-Intercept -3.143
(Limit: +-5 BHP)
Std Error 7.558
(Limit: 8%)
R-Square .94144
(Limit: 0.91)

WORK:

Actual 16.606
(Limit: -15%-5% Ref Bhp-Hr)
Reference 17.579
% Difference -5.54%

HD930096
999 D41ROUNDROBINT93 0
1B HS9E

HEAVY DUTY DIESEL TRANSIENT TEST

DATE: 04/08/93 TIME: 08:03:10 6

DIESEL SUMMARY REPORT

Test Number: HD930096 Manufacturer: EXPERIMENTAL
Test Date/Time: 4/ 7/93 10: 9 Engine ID: 999 D41ROUNDROBINT93 0

AMBIENT DATA:

Barometer: 29.21 "HG
Dry Bulb Temperature: 77.50 F
Absolute Humidity: 52.83 Grains H2O/Lbs Dry Air

EMISSION RESULTS: HS

HC (INTEGRATED):
Background, PPM 4.71
Exhaust+Bkg, Gms 12.50
Net, Gm/Bhp-Hr .584

CO (BAG):
Background, PPM 1.53
Exhaust+Bkg, Gms 17.62
Net, Gms/Bhp-Hr .95

NOX (INTEGRATED):
Background, PPM .51
Exhaust+Bkg, Gms 80.53
Net, Gms/Bhp-Hr 4.502

CO2 (BAG)
Background, PPM .034
Exhaust+Bkg, Gms 9585.03
Net, Gms/Bhp-Hr 536.2

PARTICULATE:
Secondary Tare, Gms .147942
Secondary Part, Gms .148012
Primary Tare, Gms .150209
Primary Part, Gms .153779
Total, Gms/Bhp-Hr .19

FUEL CONSUMPTION:
Lbs/Carbon Balance 6.259
Lbs/Bhp-Hr .375
Lbs/Measured 6.608

BRAKE HORSEPOWER-HOUR: 16.707

CYCLE STATISTICS: HS

SPEED:
Number 253
Slope .99247
(Limit: 0.97-1.03)
Y-Intercept 9.452
(Limit: +-50 RPM)
Std Error 17.378
(Limit: 100 RPM)
R-Square .99923
(Limit: 0.97)

TORQUE:
Number 297
Slope .96589
(Limit: 0.77/0.83-1.03)
Y-Intercept -8.578
(Limit: +-15 Ft-Lbs)
Std Error 7.646%
(Limit: 13% Max Eng Tq)
R-Square .91788
(Limit: 0.85/0.88)

POWER:
Number 253
Slope .98449
(Limit: 0.87/0.89-1.03)
Y-Intercept -3.001
(Limit: +-5 BHP)
Std Error 7.318%
(Limit: 8%)
R-Square .94529
(Limit: 0.91)

WORK:
Actual 16.707
(Limit: -15%-5% Ref Bhp-Hr)
Reference 17.579
% Difference -4.96%

HD930097
999 D41ROUNDROBINT93 0
1B hs10

HEAVY DUTY DIESEL TRANSIENT TEST

DATE: 04/08/93 TIME: 08:05:23 6

DIESEL SUMMARY REPORT

Test Number: HD930097 Manufacturer: EXPERIMENTAL
Test Date/Time: 4/ 7/93 10:39 Engine ID: 999 D41ROUNDROBINT93 0

AMBIENT DATA:

Barometer: 29.21 "HG
Dry Bulb Temperature: 77.10 F
Absolute Humidity: 54.04 Grains H2O/Lbs Dry Air

EMISSION RESULTS:

HS

HC (INTEGRATED):

Background, PPM 4.27
Exhaust+Bkg, Gms 12.15
Net, Gm/Bhp-Hr .580

CO (BAG):

Background, PPM 1.09
Exhaust+Bkg, Gms 17.35
Net, Gms/Bhp-Hr .96

NOX (INTEGRATED):

Background, PPM .51
Exhaust+Bkg, Gms 78.65
Net, Gms/Bhp-Hr 4.417

CO2 (BAG)

Background, PPM .032
Exhaust+Bkg, Gms 9585.03
Net, Gms/Bhp-Hr 539.1

PARTICULATE:

Secondary Tare, Gms .149809
Secondary Part, Gms .149909
Primary Tare, Gms .147713
Primary Part, Gms .151277
Total, Gms/Bhp-Hr .19

FUEL CONSUMPTION:

Lbs/Carbon Balance 6.282
Lbs/Bhp-Hr .377
Lbs/Measured 6.608

BRAKE HORSEPOWER-HOUR:

16.679

CYCLE STATISTICS:

HS

SPEED:

Number 258
Slope .99134
(Limit: 0.97-1.03)
Y-Intercept 11.036
(Limit: +-50 RPM)
Std Error 17.663
(Limit: 100 RPM)
R-Square .99920
(Limit: 0.97)

TORQUE:

Number 297
Slope .96962
(Limit: 0.77/0.83-1.03)
Y-Intercept -9.796
(Limit: +-15 Ft-Lbs)
Std Error 7.568
(Limit: 13% Max Eng Tq)
R-Square .92189
(Limit: 0.85/0.88)

POWER:

Number 258
Slope .98604
(Limit: 0.87/0.89-1.03)
Y-Intercept -3.168
(Limit: +-5 BHP)
Std Error 7.247
(Limit: 8%)
R-Square .94763
(Limit: 0.91)

WORK:

Actual 16.679
(Limit: -15%-5% Ref Bhp-Hr)
Reference 17.579
% Difference -5.12%

HD930098
999 D41ROUNDROBINT93 0
1B HS11

HEAVY DUTY DIESEL TRANSIENT TEST

DATE: 04/08/93 TIME: 08:07:18 6

DIESEL SUMMARY REPORT

Test Number: HD930098 Manufacturer: EXPERIMENTAL
Test Date/Time: 4/ 7/93 11: 8 Engine ID: 999 D41ROUNDROBINT93 0

AMBIENT DATA:

Barometer: 29.22 "HG
Dry Bulb Temperature: 77.50 F
Absolute Humidity: 55.05 Grains H2O/Lbs Dry Air

EMISSION RESULTS:

HS

HC (INTEGRATED):

Background, PPM 4.12
Exhaust+Bkg, Gms 11.77
Net, Gm/Bhp-Hr .561

CO (BAG):

Background, PPM 1.31
Exhaust+Bkg, Gms 17.36
Net, Gms/Bhp-Hr .95

NOX (INTEGRATED):

Background, PPM .76
Exhaust+Bkg, Gms 79.26
Net, Gms/Bhp-Hr 4.430

CO2 (BAG)

Background, PPM .034
Exhaust+Bkg, Gms 9549.51
Net, Gms/Bhp-Hr 534.3

PARTICULATE:

Secondary Tare, Gms .146455
Secondary Part, Gms .146558
Primary Tare, Gms .147103
Primary Part, Gms .150643
Total, Gms/Bhp-Hr .19

FUEL CONSUMPTION:

Lbs/Carbon Balance 6.232
Lbs/Bhp-Hr .373
Lbs/Measured 6.608

BRAKE HORSEPOWER-HOUR:

16.694

CYCLE STATISTICS:

HS

SPEED:

Number 256
Slope .99189
(Limit: 0.97-1.03)
Y-Intercept 9.346
(Limit: +-50 RPM)
Std Error 17.349
(Limit: 100 RPM)
R-Square .99923
(Limit: 0.97)

TORQUE:

Number 297
Slope .96575
(Limit: 0.77/0.83-1.03)
Y-Intercept -8.170
(Limit: +-15 Ft-Lbs)
Std Error 7.525
(Limit: 13% Max Eng Tq)
R-Square .92141
(Limit: 0.85/0.88)

POWER:

Number 256
Slope .98423
(Limit: 0.87/0.89-1.03)
Y-Intercept -2.973
(Limit: +-5 BHP)
Std Error 7.198
(Limit: 8%)
R-Square .94766
(Limit: 0.91)

WORK:

Actual 16.694
(Limit: -15%-5% Ref Bhp-Hr)
Reference 17.579
% Difference -5.03%

HD930099
999 D41ROUNDROBINT93 0
1B HS12

HEAVY DUTY DIESEL TRANSIENT TEST

DATE: 04/08/93 TIME: 08:09:26 6

DIESEL SUMMARY REPORT

Test Number: HD930099 Manufacturer: EXPERIMENTAL
Test Date/Time: 4/ 7/93 11:37 Engine ID: 999 D41ROUNDROBINT93 0

AMBIENT DATA:

Barometer: 29.21 "HG
Dry Bulb Temperature: 77.80 F
Absolute Humidity: 54.66 Grains H2O/Lbs Dry Air

EMISSION RESULTS:

HS

HC (INTEGRATED):

Background, PPM 4.12
Exhaust+Bkg, Gms 11.90
Net, Gm/Bhp-Hr .580

CO (BAG):

Background, PPM .87
Exhaust+Bkg, Gms 17.36
Net, Gms/Bhp-Hr 1.00

NOX (INTEGRATED):

Background, PPM 1.01
Exhaust+Bkg, Gms 79.46
Net, Gms/Bhp-Hr 4.489

CO2 (BAG)

Background, PPM .032
Exhaust+Bkg, Gms 9552.11
Net, Gms/Bhp-Hr 546.2

PARTICULATE:

Secondary Tare, Gms .148885
Secondary Part, Gms .148954
Primary Tare, Gms .149890
Primary Part, Gms .153414
Total, Gms/Bhp-Hr .19

FUEL CONSUMPTION:

Lbs/Carbon Balance 6.258
Lbs/Bhp-Hr .382
Lbs/Measured 6.608

BRAKE HORSEPOWER-HOUR:

16.397

CYCLE STATISTICS:

HS

SPEED:

Number 257
Slope .98805
(Limit: 0.97-1.03)
Y-Intercept 14.046
(Limit: +-50 RPM)
Std Error 47.212
(Limit: 100 RPM)
R-Square .99429
(Limit: 0.97)

TORQUE:

Number 297
Slope .93235
(Limit: 0.77/0.83-1.03)
Y-Intercept -8.655
(Limit: +-15 Ft-Lbs)
Std Error 10.153%
(Limit: 13% Max Eng Tq)
R-Square .85973
(Limit: 0.85/0.88)

POWER:

Number 257
Slope .96010
(Limit: 0.87/0.89-1.03)
Y-Intercept -3.407
(Limit: +-5 BHP)
Std Error 10.011%
(Limit: 8%)
R-Square .89981
(Limit: 0.91)

WORK:

Actual 16.397
(Limit: -15%-5% Ref Bhp-Hr)
Reference 17.579
% Difference -6.72%

CUMMINS/EPA/TAIWAN CORRELATION ENGINE -- TEST RESULTS FROM CUMMINS

Engine Model: C8.3-250 Engine S/N: 44803148 Test Cell: 301

TESTNO	DATE	BSHC	CORR BSNOX	BSCO	BSCO2	CBE	WORK	BSFC	OIL PANT	COMB AIRT	COMB VAP	BSPART	H CORR BSPART	COMMENT
A92792	H 02/01/93	.504	4.586	.655	571.901	-5.38	17.45	.3995	196.0	78.0	.494	.181	.182	PRACTICE
A92793	H 02/01/93	.540	4.576	.646	566.918	-.37	17.53	.3961	204.0	79.0	.485	.192	.193	PRACTICE
A92794	H 02/01/93	.527	4.604	.675	569.300	-.51	17.50	.3977	203.0	77.0	.492	.205	.205	PRACTICE

STATISTICS - 3 PRACTICE CYCLES

AVE	.524	4.589	.658	569.373	-2.08	17.49	.3978	201.0	78.0	.490	.193	.193	
STDEV	.018	.014	.015	2.492	2.85	.04	.0017	4.4	1.0	.005	.012	.012	
# SAMP	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	

A92920	C 02/02/93	.531	4.758	1.170	586.586	.83	17.39	.4103	83.0	77.0	.498	.212	.212	COLD
A92921	H 02/02/93	.534	4.636	.841	568.470	-.08	17.51	.3974	162.0	77.0	.498	.185	.186	HOT-1
C/H		.534	4.653	.888	571.0		<i>17.49 C.3992</i>					.189		C/H SUMM'Y

A92922	H 02/02/93	.538	4.636	.942	572.694	-.51	17.47	.4004	195.0	77.0	.484	.187	.188	HOT-2
A92923	H 02/02/93	.533	4.630	.948	569.790	.25	17.47	.3984	198.0	77.0	.495	.191	.191	HOT-3
A92924	H 02/02/93	.504	4.600	.947	572.233	.19	17.41	.4000	198.0	77.0	.489	.187	.188	HOT-4
A92925	H 02/02/93	.529	4.612	.950	572.199	.14	17.43	.4001	195.0	77.0	.494	.183	.184	HOT-5

STATISTICS - 5 HOT CYCLES

AVE	.528	4.623	.926	571.077	.00	17.46	.3992	189.6	77.0	.492	.187	.187	
STDEV	.013	.016	.047	1.846	.31	.04	.0013	15.5	.0	.006	.003	.003	
# SAMP	5.	5.	5.	5.	5.	5.	5.	5.	5.	5.	5.	5.	

G.L.GREEN/C.A.FEUCHT - 05FEB93

17.13517

6.958474

17.44