1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

DDC ALTERNATIVE FUEL PRODUCT EXPERIENCE AND FURTHER DEVELOPMENT

S.P. Miller
Detroit Diesel Corporation

DDC ALTERNATE FUEL ENGINES

IN SERVICE

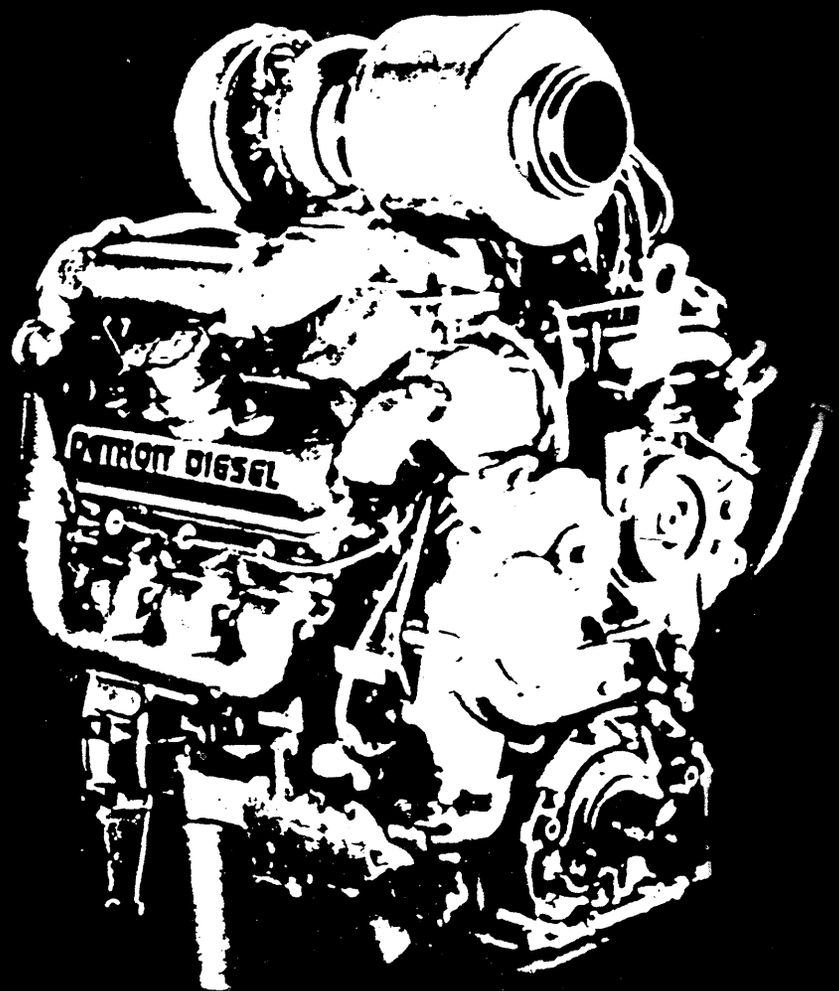
	METHANOL	ETHANOL	CNG	LNG
TRUCKS	7	5	2	0
BUSES	454	21	38	~~15~~ 30

DELIVERIES IN PROCESS

TRUCKS	0	4	2	0
BUSES	108	3	16	180

DDC

6V-92TA ALCOHOL FUELED ENGINE



METHANOL ENGINE EMISSIONS

	G/HP-HR			
	HC	CO	NOx	PM
1998 TRUCK STANDARDS	1.3	15.5	4.0	0.10
METHANOL ENGINE CERTIFICATION RESULTS	0.08	2.0	1.7	0.03

DDC

METHANOL ENGINE DATA

	BUSES	TRUCKS
NUMBER OF UNITS	454	7
TOTAL MILES	>10 MILLION	>250,000
ENERGY CONSUMPTION RATIO (METHANOL : DIESEL)	1.03 - 1.30	1.0 - 1.20

TANK VOLUME VS. DIESEL FOR EQUAL RANGE: 2.3 - 2.7 × GREATER

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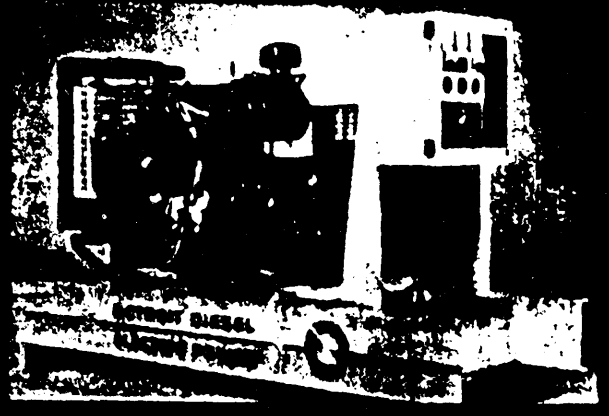
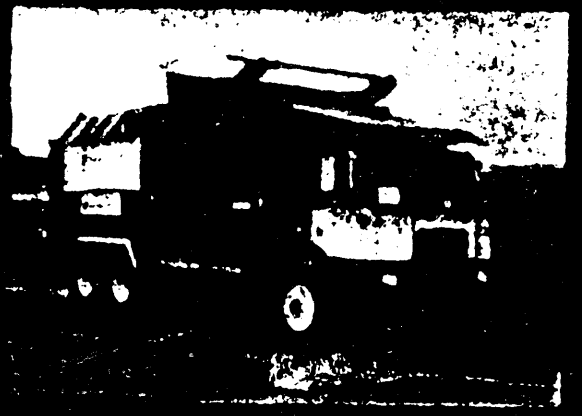
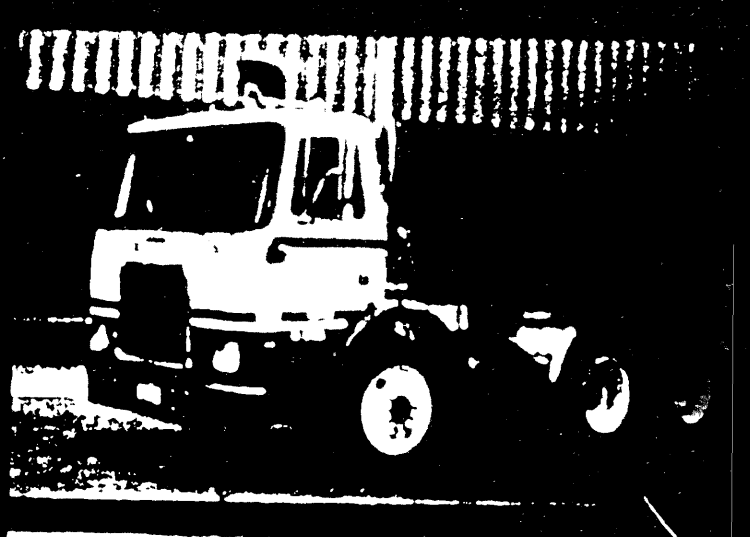
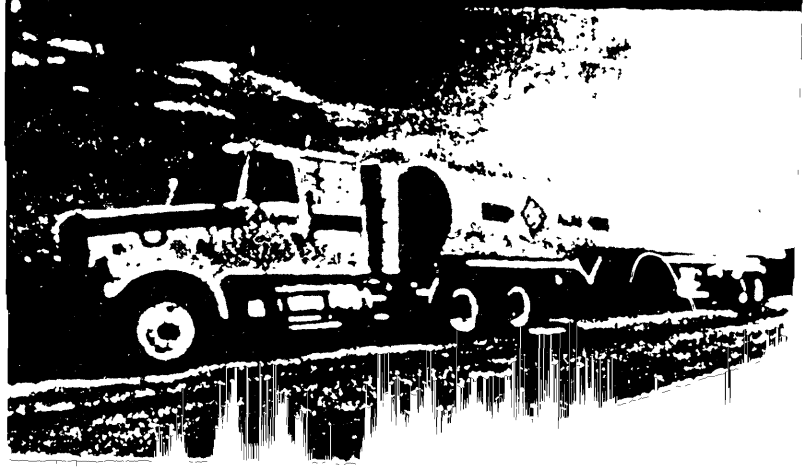
METHANOL ENGINE APPLICATIONS





ETHANOL ENGINE APPLICATIONS





ETHANOL ENGINE EMISSIONS

	G/HP-HR			
	HC	CO	NOx	PM
1998 TRUCK STD.	1.3	15.5	4.0	0.10
ETHANOL ENGINE CERTIFICATION RESULTS	0.7	1.7	4.2	0.04
ETHANOL ENGINE DEVELOPMENT RESULTS	0.3	1.7	3.7	0.04

DDC

ETHANOL ENGINE DATA

	BUSES	TRUCKS
NUMBER OF UNITS	21	5
TOTAL MILES	400,000	430,000
ENERGY CONSUMPTION RATIO (ETHANOL : DIESEL)	1.0 - 1.1	1.0 - 1.1

TANK VOLUME VS. DIESEL FOR EQUAL
RANGE: 1.7 - 1.9 × GREATER

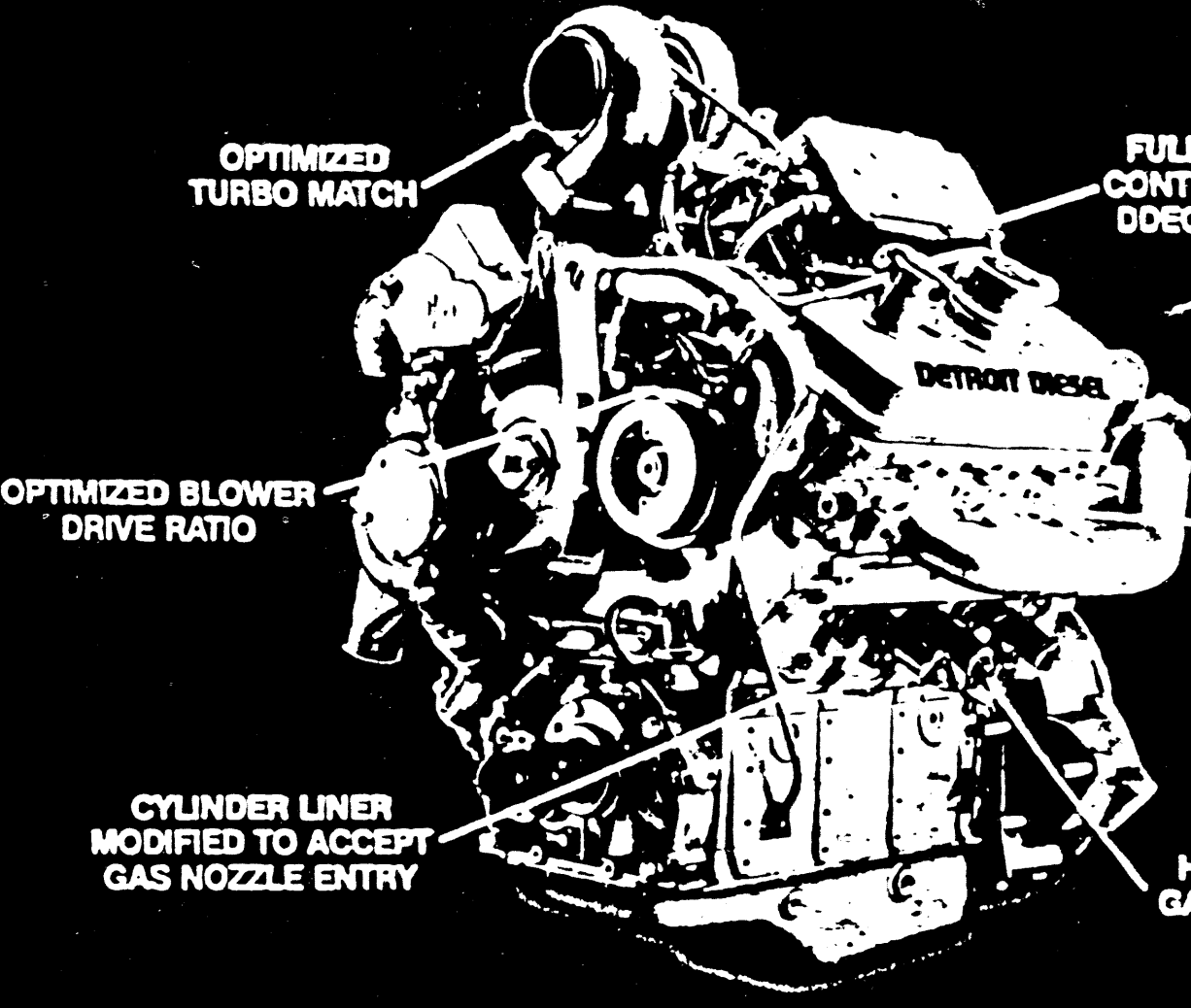
DDC

DETROIT DIESEL CORPORATION
NATURAL GAS ENGINE PROGRAM

- PILOT IGNITION 6V-92TA
- DIRECT INJECTION 6V-92TA
- SPARK IGNITION S-50
- SPARK IGNITION S-30

DDC

PILOT IGNITION
NATURAL GAS BUS ENGINE



OPTIMIZED TURBO MATCH

FULL ELECTRONIC CONTROL OPTIMIZED DDEC CALIBRATION

OPTIMIZED BLOWER DRIVE RATIO

15:1 COMPRESSION RATIO

CYLINDER LINER MODIFIED TO ACCEPT GAS NOZZLE ENTRY

HIGH SPEED GAS INJECTOR

DDC

PILOT IGNITION NATURAL GAS ENGINE EMISSIONS

DEVELOPMENT RESULTS

	G/HP-HR			
	HC	CO	NOx	PM
1994 BUS STD.	1.3	15.5	5.0	.07
PI-NG ENGINE	0.9	0.3	4.8	0.07

DDC

PILOT IGNITION NATURAL GAS ENGINE

	BUSES	TRUCKS
NUMBER OF UNITS	108	2
TOTAL MILES	1.5 MILLION	60,000
ENERGY CONSUMPTION RATIO (NATURAL GAS : DIESEL)	1.05	1.05

TANK VOLUME VS. DIESEL FOR EQUAL RANGE:
- CNG - 4.7 × GREATER
- LNG - 1.7 × GREATER

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ALTERNATE FUEL DURABILITY EXPERIENCE

	METHANOL	ETHANOL	NATURAL GAS
MAXIMUM MILES ON ROAD	185,000	112,000	83,000
TEARDOWN INSPECTION @ 100,000 MILES	YES	-	-

METHANOL TEARDOWN RESULTS

- RING & LINER WEAR EQUAL TO DIESEL
- BEARING WEAR SLIGHTLY HIGHER THAN DIESEL

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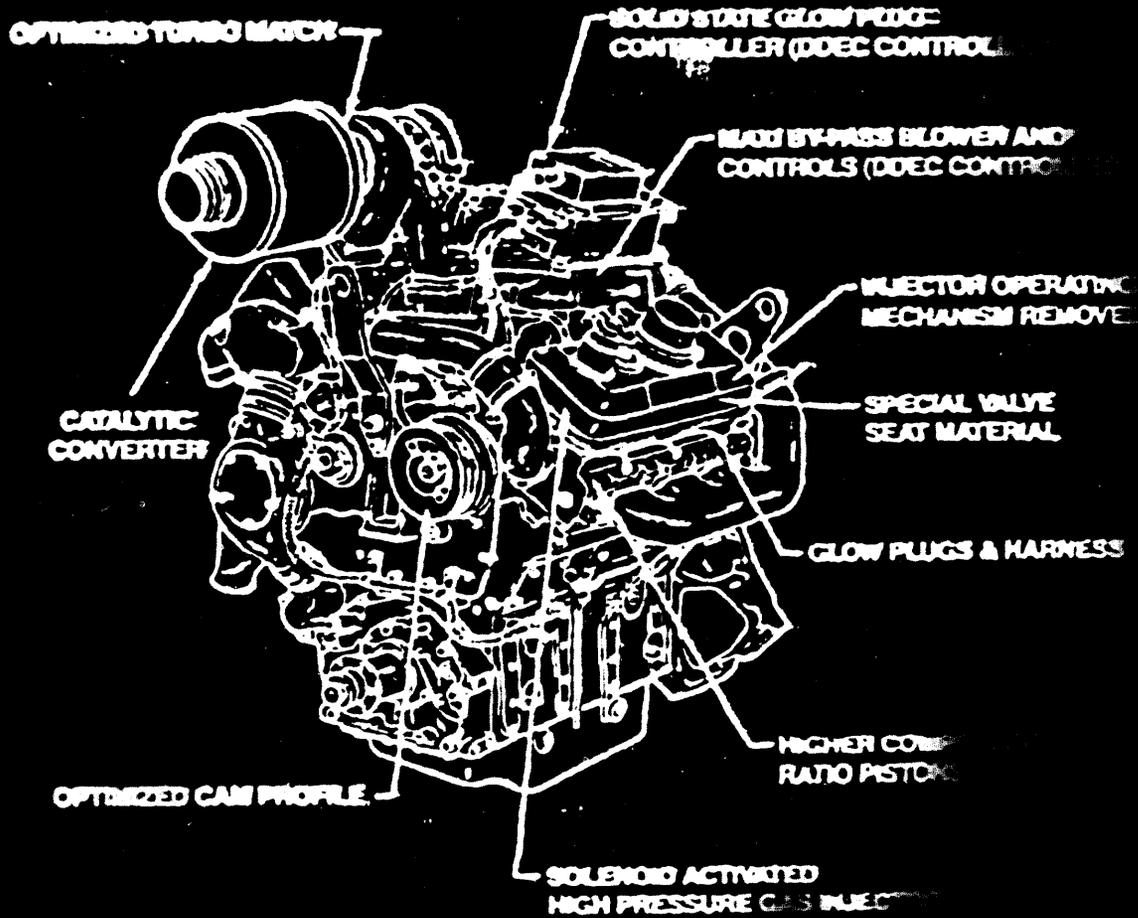
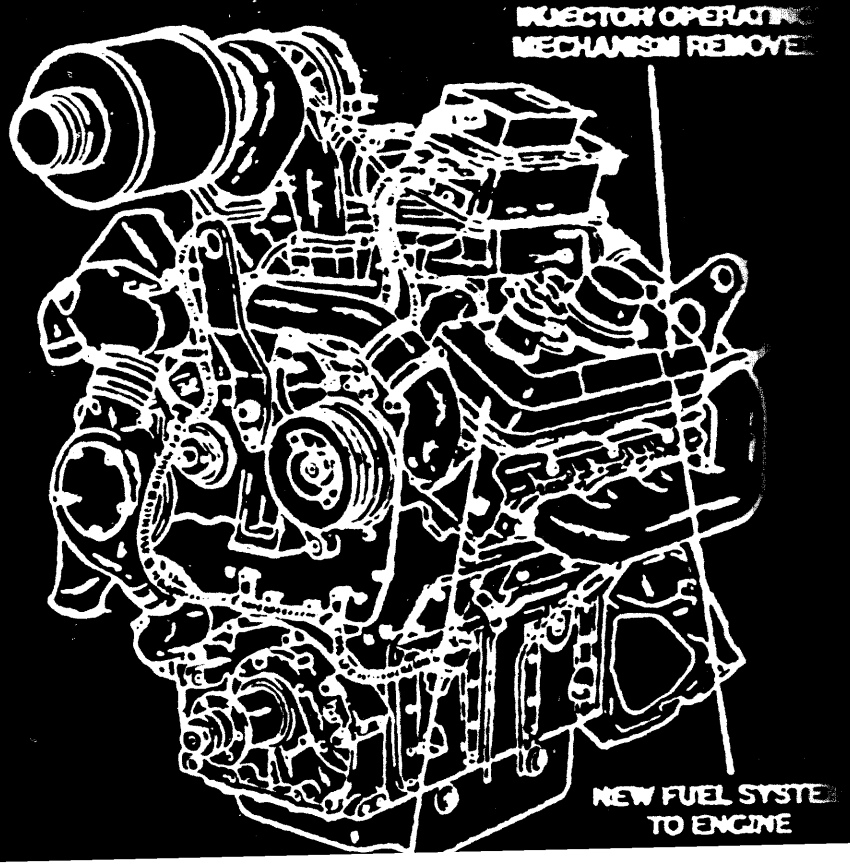
DIRECT INJECTION NATURAL GAS BUS ENGINE

HARDWARE CHANGES vs. DIESEL



DIRECT INJECTION NATURAL GAS BUS ENGINE

HARDWARE CHANGES vs. METHANOL



DIRECT INJECTION NATURAL GAS ENGINE EMISSIONS

	G/HP-HR			
	HC	CO	NOx	PM
1994 STANDARD	1.3	15.5	5.0	0.10
1998 STANDARD	1.3	15.5	4.0	0.10
DI-NG EMISSION TARGETS	0.6	2.0	2.5	0.05

DDC

FAMILY OF SI-NG ENGINES

MODEL	DISPLACEMENT (LITERS)	HP RANGE	EPA CLASS
S-30G (NAVISTAR V8)	7.3	200-250	LIGHT-HEAVY
S-40G (NAVISTAR I-6)	8.7	250-300	MEDIUM-HEAVY
S-50G	8.5	250-300	HEAVY-HEAVY
S-60G	12.7	300-400	HEAVY-HEAVY

DDC

GENERAL SI-NG ENGINE FEATURES

- LEAN BURN COMBUSTION TECHNOLOGY
- COMPRESSION RATIO 10:1
- AIR-TO-AIR CHARGE COOLING
- TURBOCHARGED WITH WASTEGATE CONTROL
- ELECTRONIC IGNITION, INJECTION AND THROTTLE CONTROLLED THROUGH DDEC
- FULL DDEC CAPABILITIES

DDC

DEVELOPMENT STATUS

S-50G

- LEAD DEVELOPMENT ENGINE IN FAMILY
- IMPRESSIVE EFFICIENCY, KNOCK-FREE PERFORMANCE AT HIGH POWER DENSITY DEMONSTRATED
- FIRST ENGINE DELIVERED FOR CUSTOMER DEMO APRIL 9, 1993
- TARGETED START OF FULL PRODUCTION APRIL 1, 1994

S-30G

- AGREEMENT SIGNED WITH NAVISTAR FOR DEVELOPMENT, PRODUCTION & MARKETING OF THIS ENGINE
- BASELINE DEVELOPMENT DONE AT RICARDO
- TEST SCHOOL BUS INSTALLATION COMPLETED IN JUNE, 1992
- TARGETED START OF FULL PRODUCTION JANUARY 1, 1995

DDC

4-71T METHANOL ENGINE

- PROGRAM FUNDED BY THE SCAQMD
- USES METHANOL + AVOCET IGNITION IMPROVER
- BASED ON LAC-MTA 6V-92 M + A EXPERIENCE
- COMPONENT CHANGES TO MINIMIZE THE AMOUNT OF AVOCET REQUIRED
  - 23:1 COMPRESSION RATIO
  - LOWER DISPLACEMENT BLOWER
- HIGH OUTPUT MUI INJECTORS DELIVER 160 HP
- APPLICATIONS TO DATE
  - GENERATOR SET
  - AIRPORT SHUTTLE BUS
- FOLLOW ON PROGRAM UNDERWAY TO DEVELOP DDEC VERSION @ 200 HP FOR PORT OF LONG BEACH YARD TRACTORS

DDC

8V-92TA ETHANOL TRUCK ENGINE

- DEVELOPMENT-ONLY PROGRAM FUNDED BY THE GREAT LAKES GOVERNORS COUNCIL
- BASED ON THE 6V-92TA ETHANOL ENGINE (USES THE SAME PISTONS, INJECTORS, GLOW PLUG CONTROLLERS, ETC.)
- USES CYLINDER HEADS & BYPASS BLOWER FROM HIGH OUTPUT MILITARY DIESEL ENGINE
- STATUS - CONTRACT AWARDED IN MAY, ACTIVITY JUST BEGINNING

DDC

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

DDC ALTERNATIVE FUEL PRODUCT EXPERIENCE AND FURTHER DEVELOPMENT

S.P. Miller, Detroit Diesel Corporation

Q. Robert Last, FEV of America: Could you comment on maximum thermal efficiency observed? Also, how does thermal efficiency change at part load operation compared to a conventional diesel engine?

A. The peak thermal efficiency was about 30 to 40 percent which is slightly less than the diesel at full load. However, as load decreases, the thermal efficiency of the gas engine is slightly better than the diesel engine.

Q. Ron Bright, Ford Motor Co. Canada: Is your work with liquefied natural gas related to the availability of fuel in Texas?

A. The main factor is that Houston Metro has selected LNG as a test fuel with potential for being used for their entire fleet. They have arranged for a fuel supply near Houston. Our work is being done to respond to a customer request.

Q. Joseph Wagner, NYSERDA: What is the commercial potential for the direct injection engine?

A. We need to demonstrate reliability of the engine. We would expect this technology to be used in off-highway applications of the larger engines.

Q. What about transit bus applications?

A. We will have competing technologies for awhile and the outcome depends on a lot of things such as engine cost and fuel efficiency.

Q. Anonymous: Are you testing vegetable oils or bio-diesel fuels?

A. Yes, we are working with esterified vegetable oil as possible blending agents. They add oxygen to the diesel fuel to reduce particulates in the exhaust. They may also increase the NOx emissions although injection timing adjustment can compensate for that effect. We have also tested bio-diesel as pilot fuel for ignition of natural gas.

Q. Mostafa Kamel, Cummins Engine Co.: Could you comment on pressure levels for LNG injection?

A. There are a couple of candidate fuel systems being developed, tentatively with 50 to 70 psi pressure range.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

DEDICATED NATURAL GAS ENGINES FOR ON-HIGHWAY APPLICATIONS "THE NATURAL CHOICE"

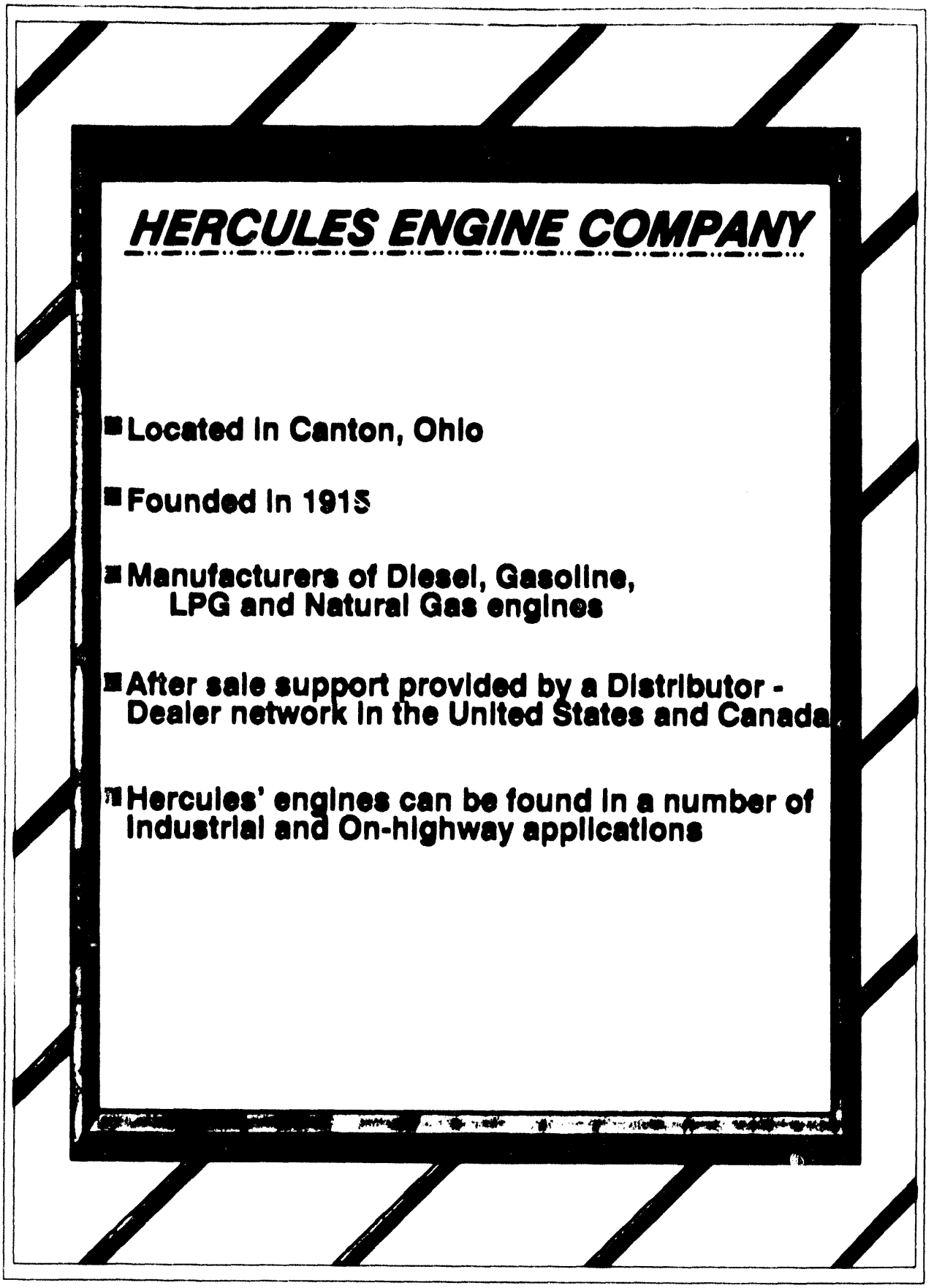
K. Boyer
Hercules Engine Company

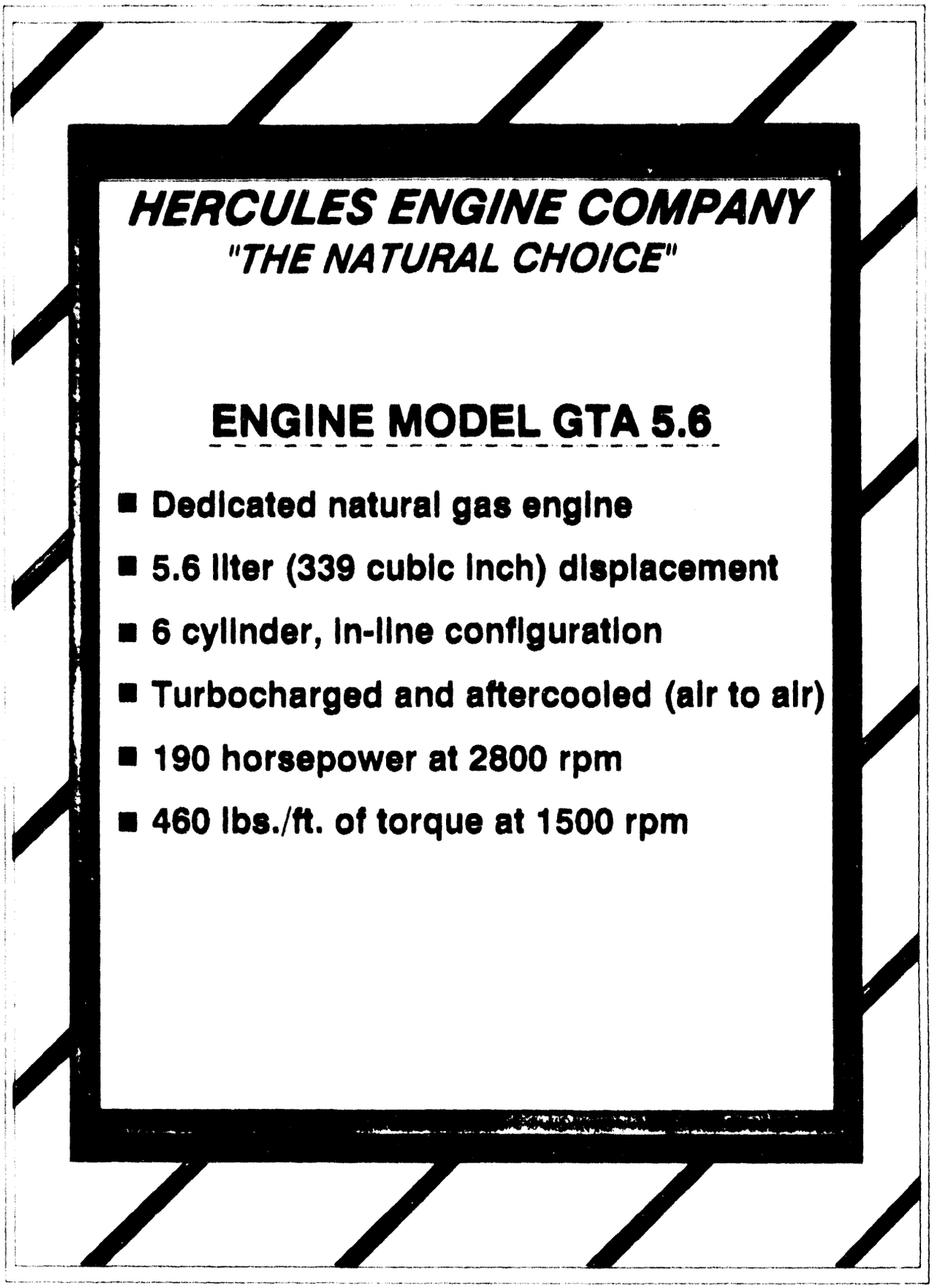
NOVEMBER 25, 1992

HERCULES ENGINES, INC.

TO

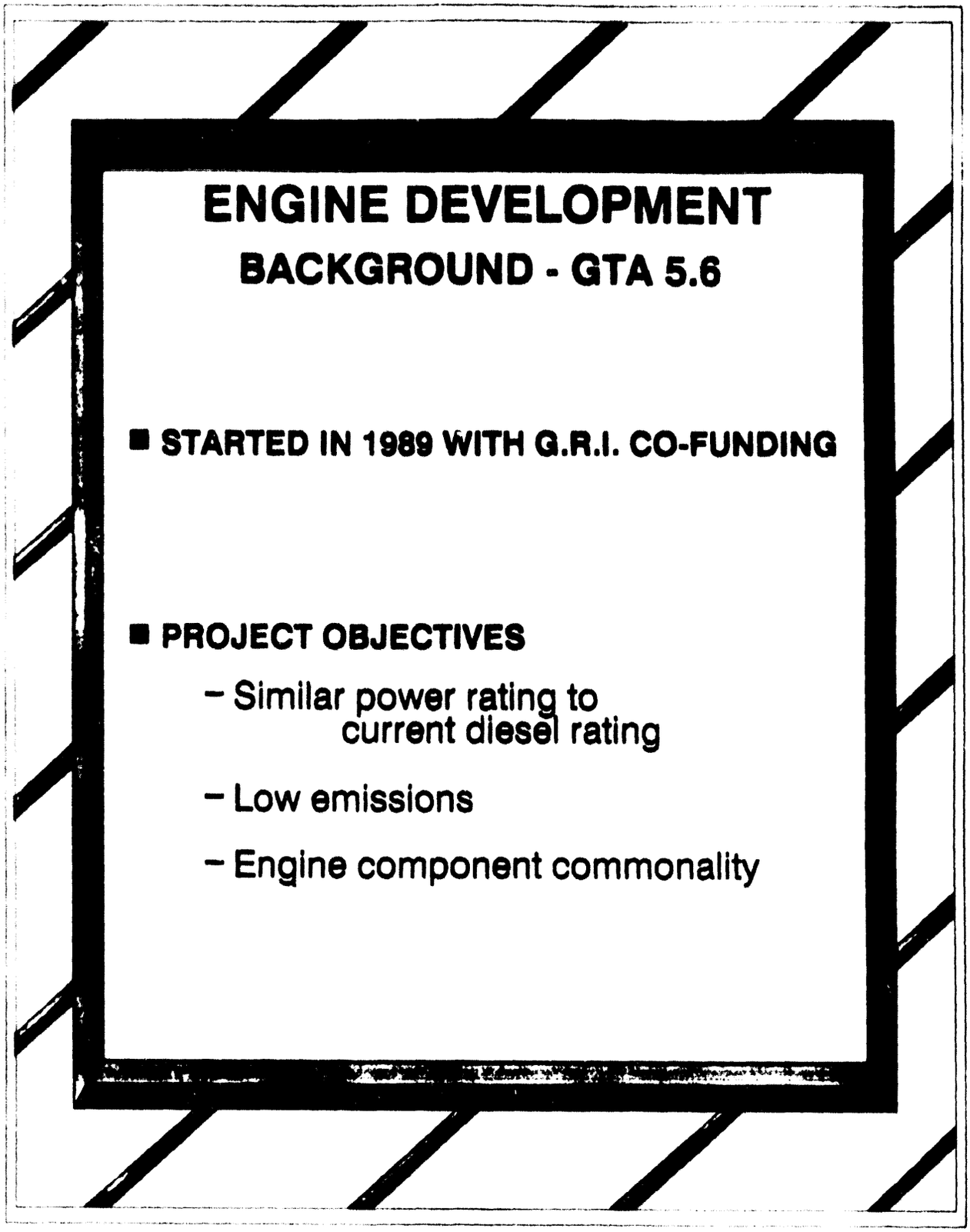
HERCULES ENGINE COMPANY


HERCULES ENGINE COMPANY
Located in Canton, Ohio
Founded in 1915
Manufacturers of Diesel, Gasoline, LPG and Natural Gas engines
After sale support provided by a Distributor - Dealer network in the United States and Canada
Hercules' engines can be found in a number of Industrial and On-highway applications


HERCULES ENGINE COMPANY
"THE NATURAL CHOICE"
ENGINE MODEL GTA 5.6
■ Dedicated natural gas engine
■ 5.6 liter (339 cubic inch) displacement
■ 6 cylinder, in-line configuration
■ Turbocharged and aftercooled (air to air)
■ 190 horsepower at 2800 rpm
■ 460 lbs./ft. of torque at 1500 rpm

HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"



HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"

ENGINE DEVELOPMENT

BACKGROUND - GTA 5.6

	EPA 1991 Diesel	Hercules Natural Gas
NOx	5.0	1.68
THC	1.8	13.7
NMHC	N/A	1.3
CO	15.5	3.6
PM	0.25	0.1

- Success stimulated further development

HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"

ENGINE DEVELOPMENT

BACKGROUND - GTA 5.6

- **MECHANICAL REFINEMENTS**
  - Iron plated piston crown
  - Revised piston skirt profile
  - Reduced oil consumption ring set
  - Modified valve stem oil seals
  - Electronic fuel-ignition control

HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"

ENGINE DEVELOPMENT

BACKGROUND - GTA 5.6

- **KEY TO LOWEST EMISSIONS**
  - Cyl. to Cyl. air/fuel ratio consistency
- **FUEL SYSTEM**
  - Electronic air/fuel ratio control
- **IGNITION SYSTEM**
  - 12 volt, capacitive discharge

HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"

ENGINE DEVELOPMENT

BACKGROUND - GTA 5.6

- **DEVELOPMENT SUB-CONTRACTORS**
  - ORTECH International
  - Southwest Research Institute
- **FINAL CONFIGURATION**
  - Primarily diesel components
  - Open loop electronic fuel and ignition control
  - 10:1 Compression ratio pistons
  - Lean burn combustion

TRANSIENT EMISSION TESTING

ENGINE OUT EMISSIONS

Grams/Hp/Hr.

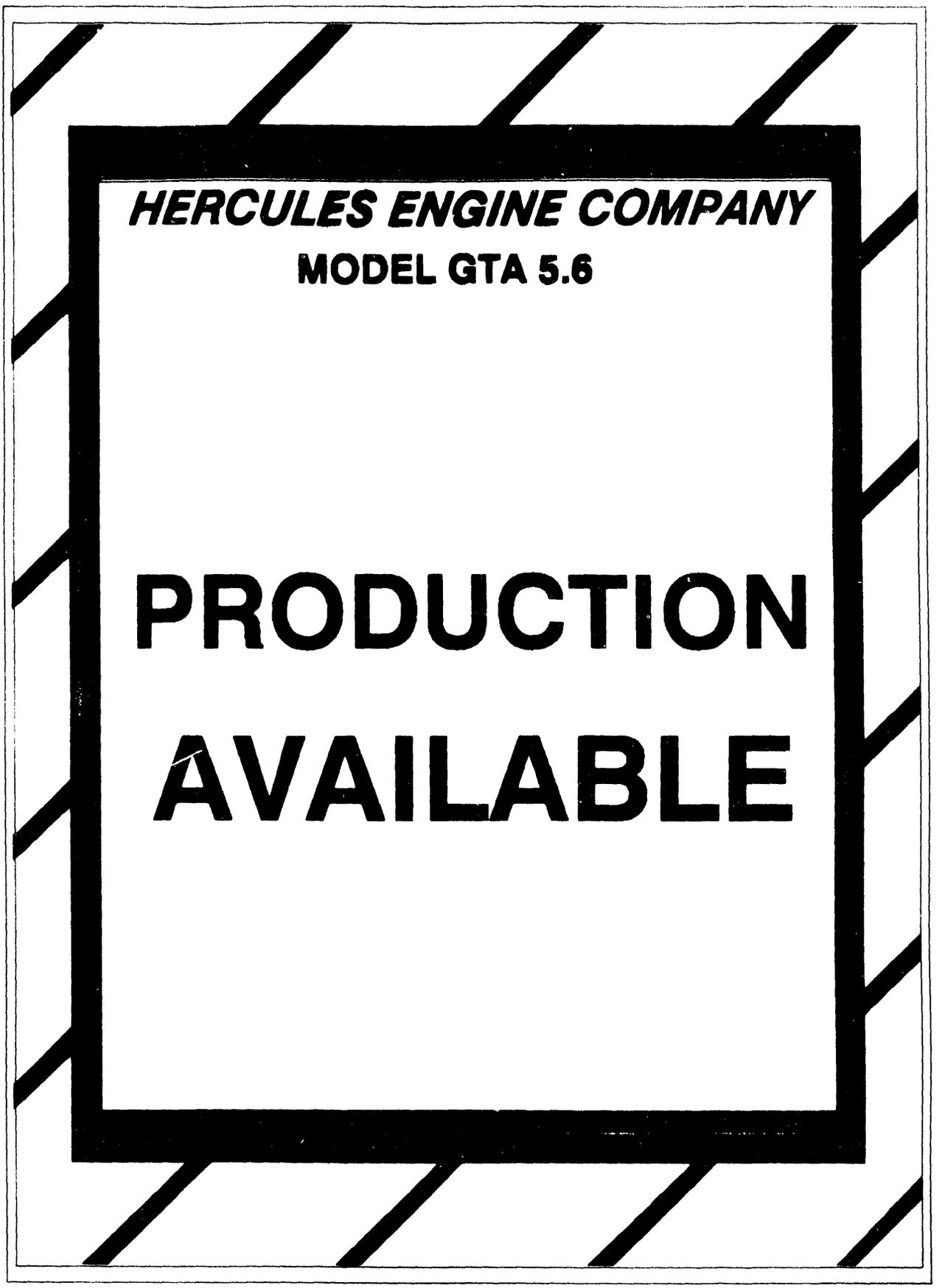
	GTA 5.6	1994 CARB
NOx	1.56	5.0
THC	3.97	1.3
NMHC	0.76	1.2
CO	2.09	15.5
PM	0.06	0.1

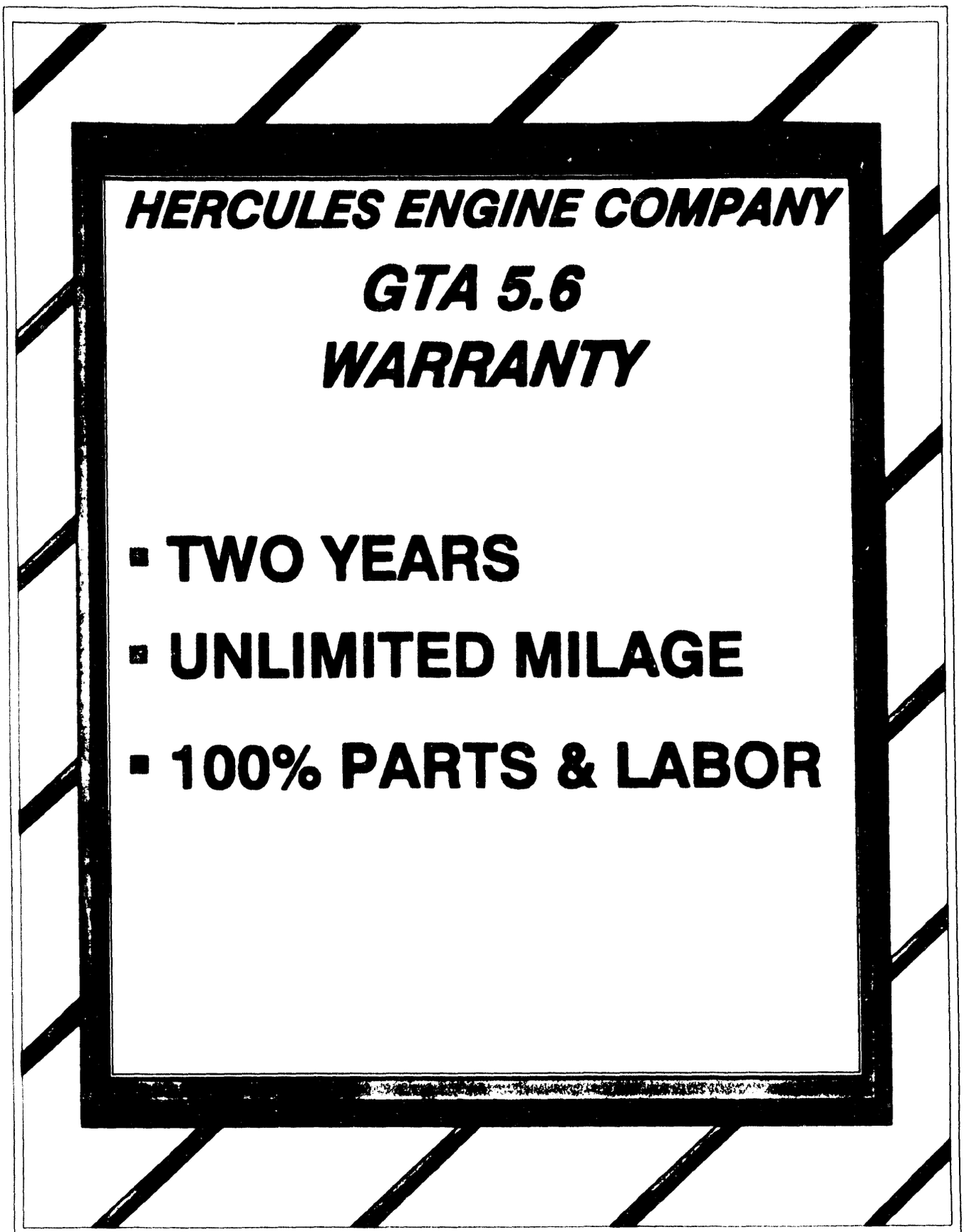
HERCULES ENGINE COMPANY
MODEL GTA 5.6

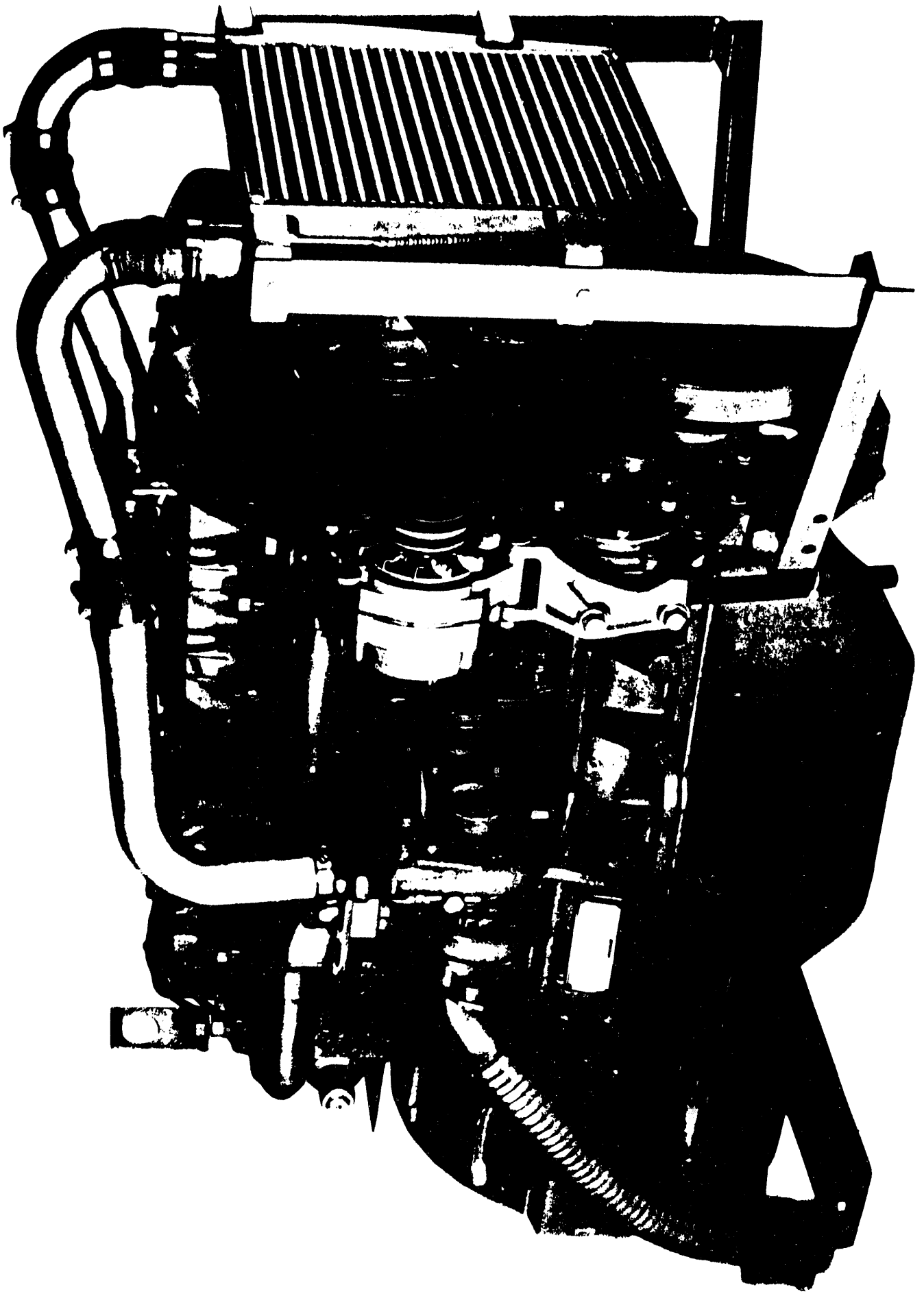
STATE OF CALIFORNIA
AIR RESOURCES BOARD

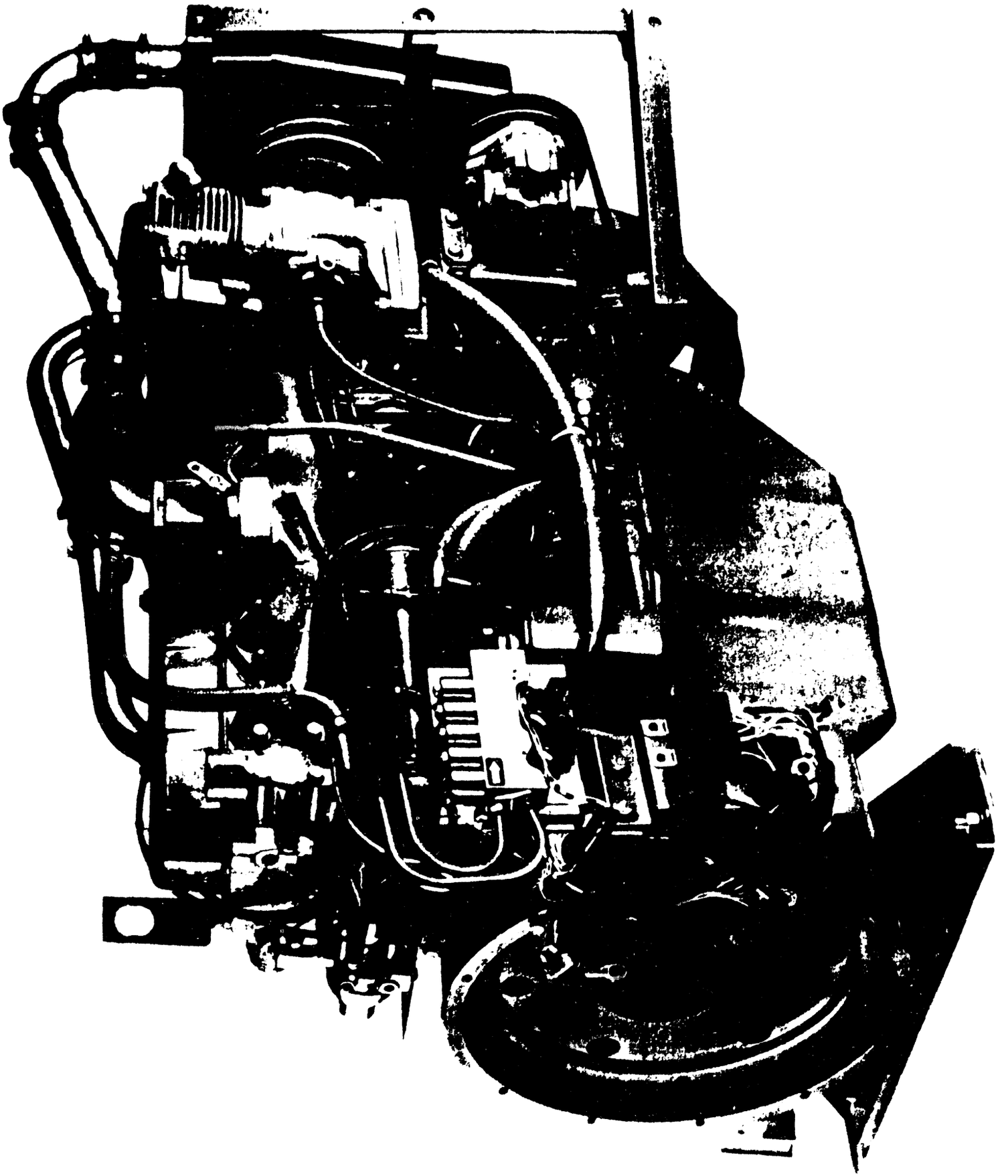
EXECUTIVE ORDER
A-289-3

Issued on March 30, 1993


HERCULES ENGINE COMPANY
MODEL GTA 5.6
PRODUCTION
AVAILABLE


HERCULES ENGINE COMPANY
GTA 5.6
WARRANTY
▪ TWO YEARS
▪ UNLIMITED MILAGE
▪ 100% PARTS & LABOR



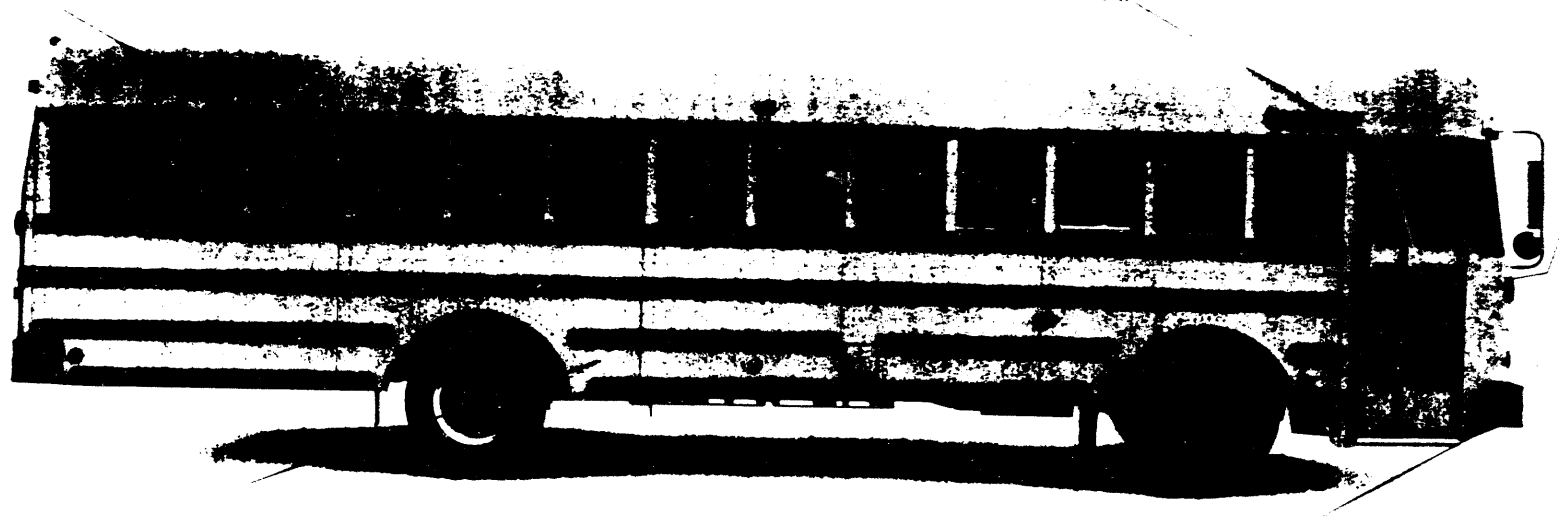


Counselor. The Student Body by Carpenter that goes the distance in efficiency.

Extra-large, aluminum split sash Hehr® passenger windows open fully to provide ample escape exits in case of an emergency.

A panoramic windshield, combined with forward placement of the driver's seat and a flat faced front end, maximizes the driver's field of vision.

Electric powered windshield wipers keep the windshield clear in rain or snow.



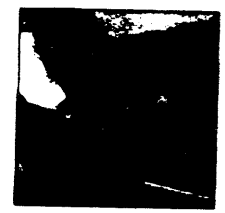
Deep side skirts accommodate large underfloor storage compartments which make Counselor well suited for transporting students to out-of-town school activities.

A wraparound, 12-inch bumper provides added protection in the event of a front-end collision.

The front grill and dual-maintenance panels can be removed without tools for easy access to electrical components, heaters, windshield washers and other front-end maintenance components.

A wide, low-angled, three-step staircase facilitates entry and exit and the low-profile engine cover expands the driver's control on- and off-loading passengers.

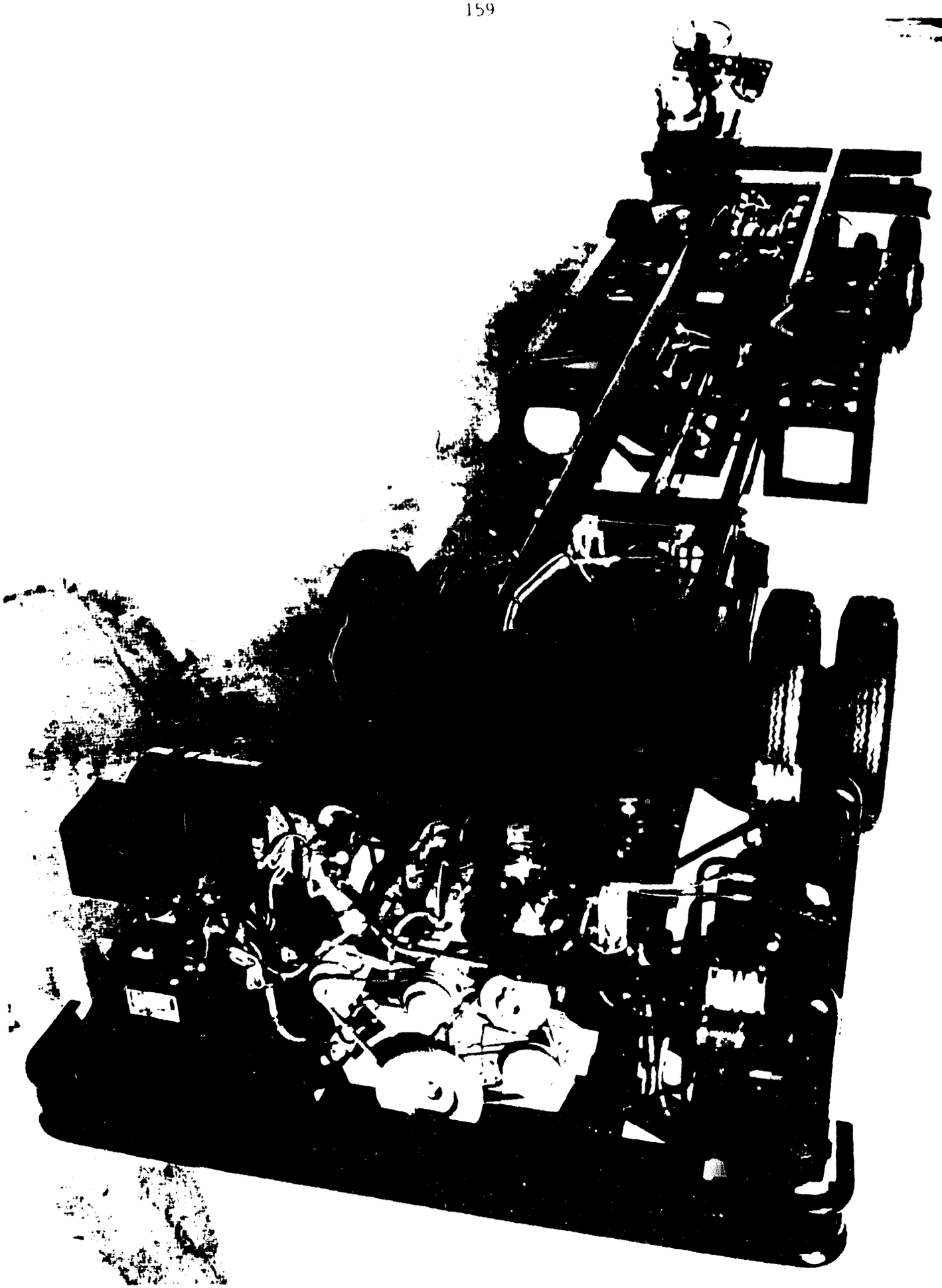
No tools are needed for the removal of the front grill and dual-maintenance access panels.



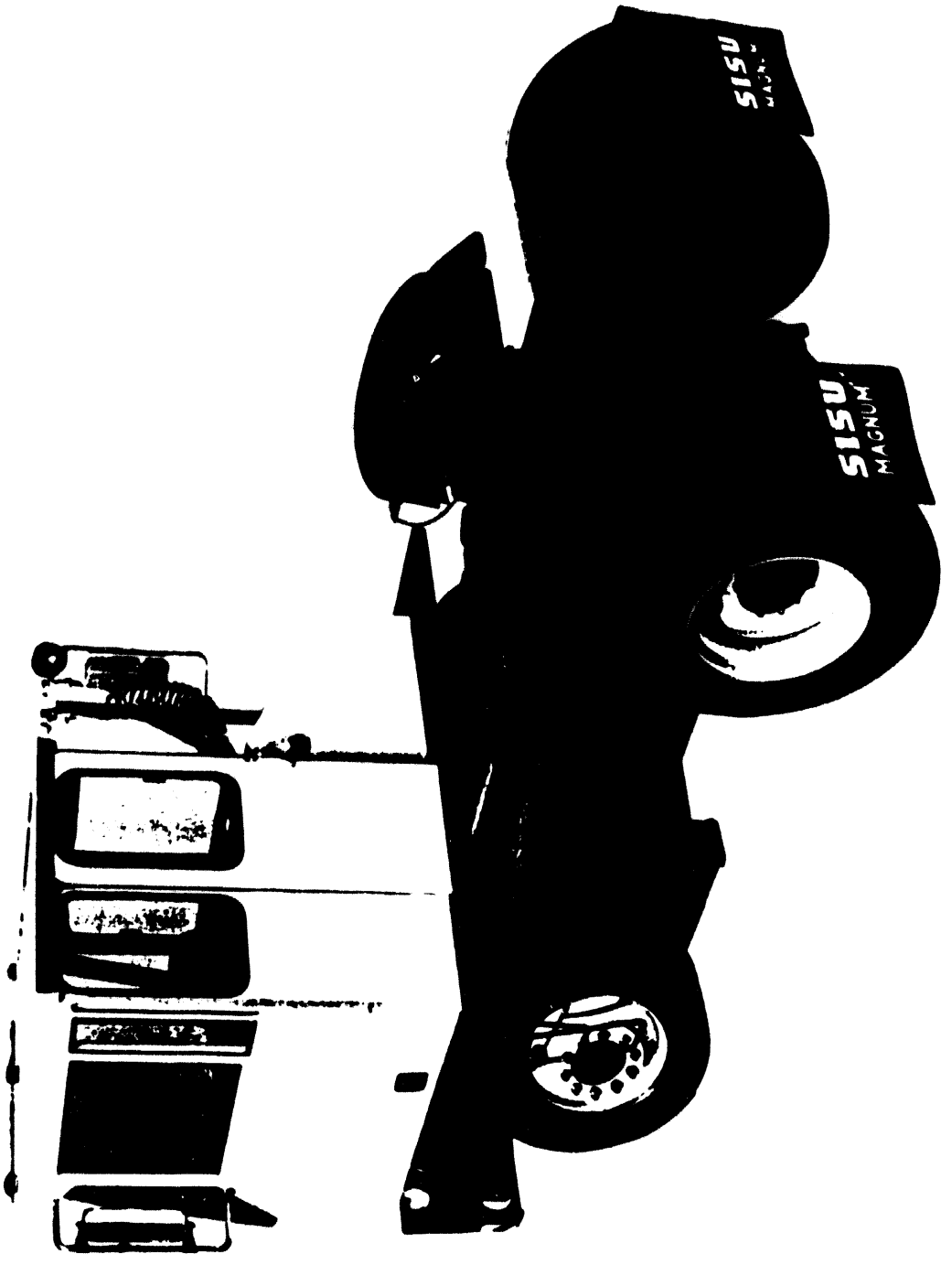
There's ample room for luggage, band instruments or athletic equipment in Counselor's optional deep side-skirt luggage compartment.

Counselor is available with an efficient Hercules dedicated Compressed Natural Gas (CNG) engine that's kinder to both your fuel budget and the environment.

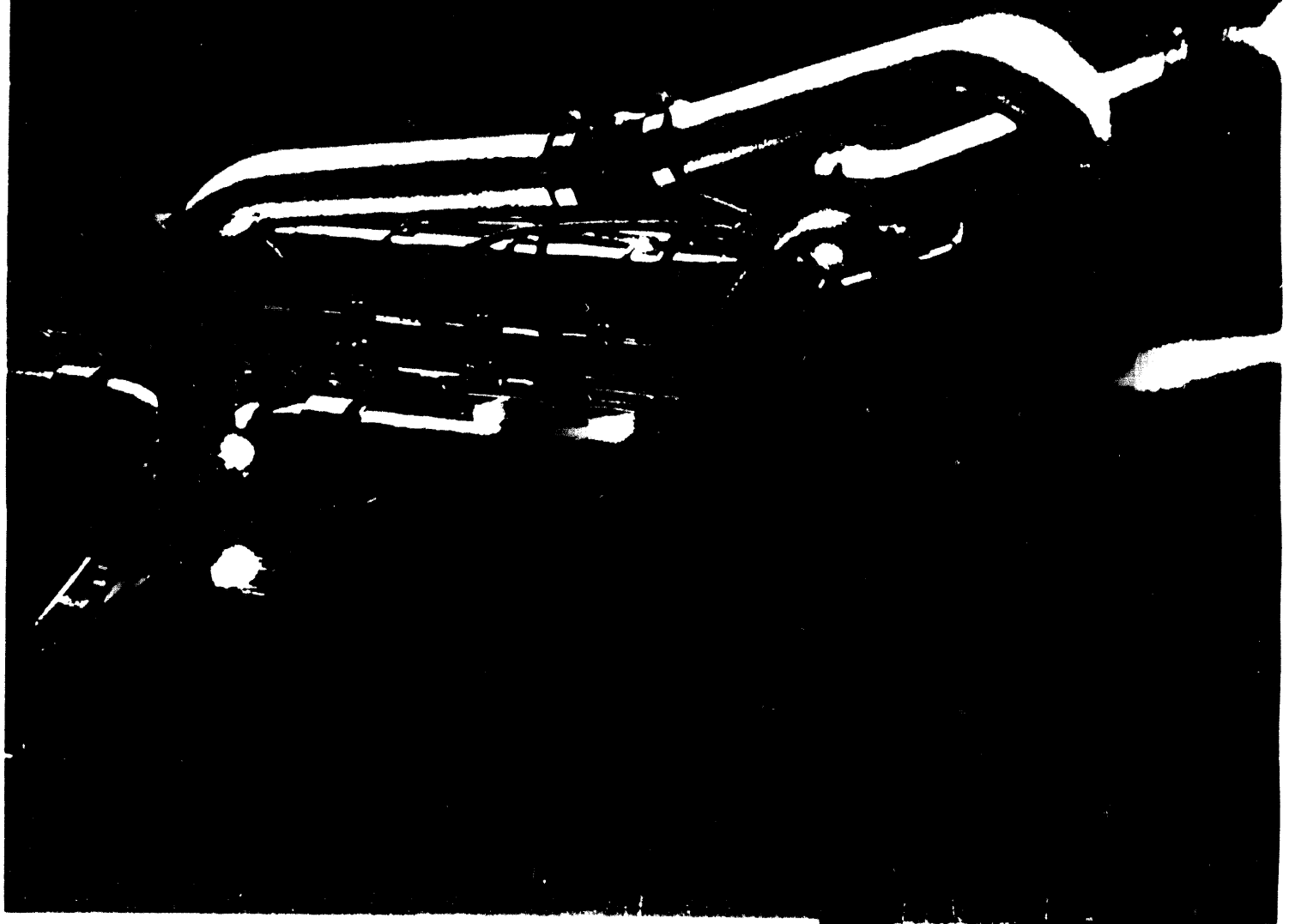

LADOT
DASH




SCHOOL BUS


SISU
SISU
MAGNUM

THE NATURAL CHOICE



Hercules is one of the [illegible] experienced manufacturers of [illegible] engines designed for a variety of applications.

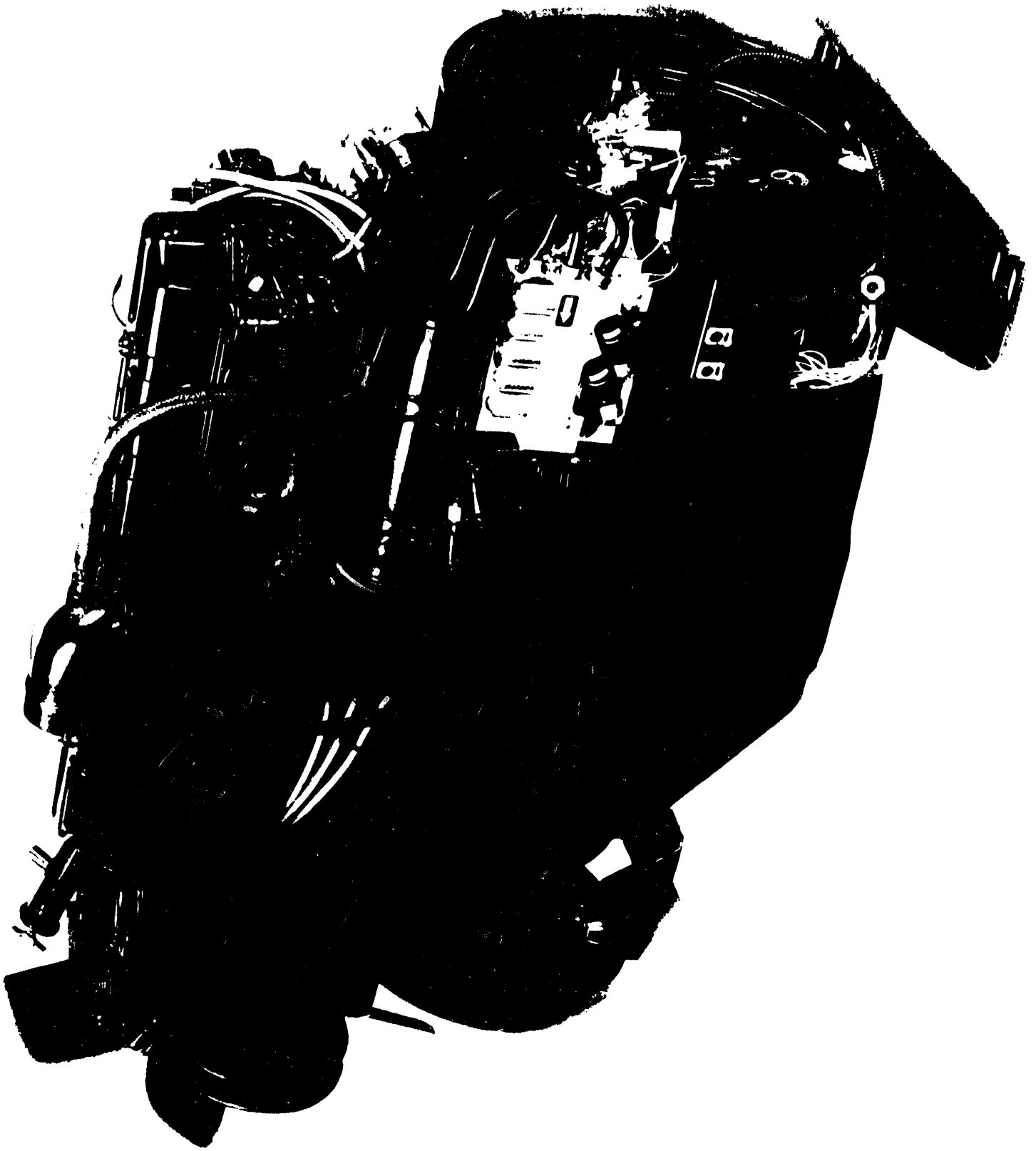
Hercules Engine Company
101 Eleventh Street, S.E. • Canton, Ohio 44707-3802
(216) 454-5631 • FAX (216) 438-1314

HERCULES
ENGINE COMPANY

PUTTING POWER TO WORK

HERCU


HERCULES
ENGINES INC



SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

DEDICATED NATURAL GAS ENGINES FOR ON-HIGHWAY APPLICATIONS - THE NATURAL CHOICE
K. Boyer, Hercules Engine Company

Q. Mostafa Kamal, Cummins Engine Co: Could you comment on gas supply pressure to the engine?

A. Yes, the system requires 100 psi at the intake side of the regulator.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

NATURAL GAS ENGINE AND VEHICLE DEVELOPMENT AT NAVISTAR PROGRAM STATUS

R.A. Baranescu
Navistar International

- Introduction - Market Forces Toward Natural Gas Fuel
- Natural Gas Engine Concept Development At Navistar
- Field Demonstration Of CNG Vehicles
- Natural Gas Engine Production Development
- Summary And Conclusions

NAVISTAR CNG ENGINE PROGRAM
MARKET FORCE INFLUENCE ON NAVISTAR

- 50% Share On School Bus Market
- 35% Share On Medium Truck Market
- 25% Share Of Heavy Truck Market
- Largest Volume Diesel Engine Producer
- Navistar Holds A Leadership Position And Responsibility

NAVISTAR CNG ENGINE PROGRAM
NAVISTAR'S MARKET STUDY

- A Sizable CNG Engine Market Exists Both Due To Mandates And Customer Benefit Reasons
- Initial Application To Centrally Fueled Fleets, Buses, Delivery Trucks, Etc.
- Must Meet EPA And California Emission Standards
- Customers Require Low Cost Of Ownership
- No Loss Of Power, Performance, Range, Driveability, Etc. Is Acceptable
- Use Commercially Available Fuel

NAVISTAR CNG ENGINE PROGRAM
DESIGN FEATURES

Power and Speed	210 HP @ 2800 RPM
Torque	450 Ft. Lb. @ 1800 RPM
Compression Ratio	10 to 11.3
Combustion	Lean Burn
Fuel Efficiency	30% Better Than Gasoline 15% Worse Than Diesel
Emission Goal	Meet EPA & California Standards
Intercooling	Only Later
Catalyst	Not Planned; Possibly Later
Fuel System	Mechanical Mixer For Veh. Demo Electronic Gas Valve For Prod. Dev.
Ignition	High Energy CD For Veh. Demo Automotive Induction System For Prod. Dev.

RB6B_593

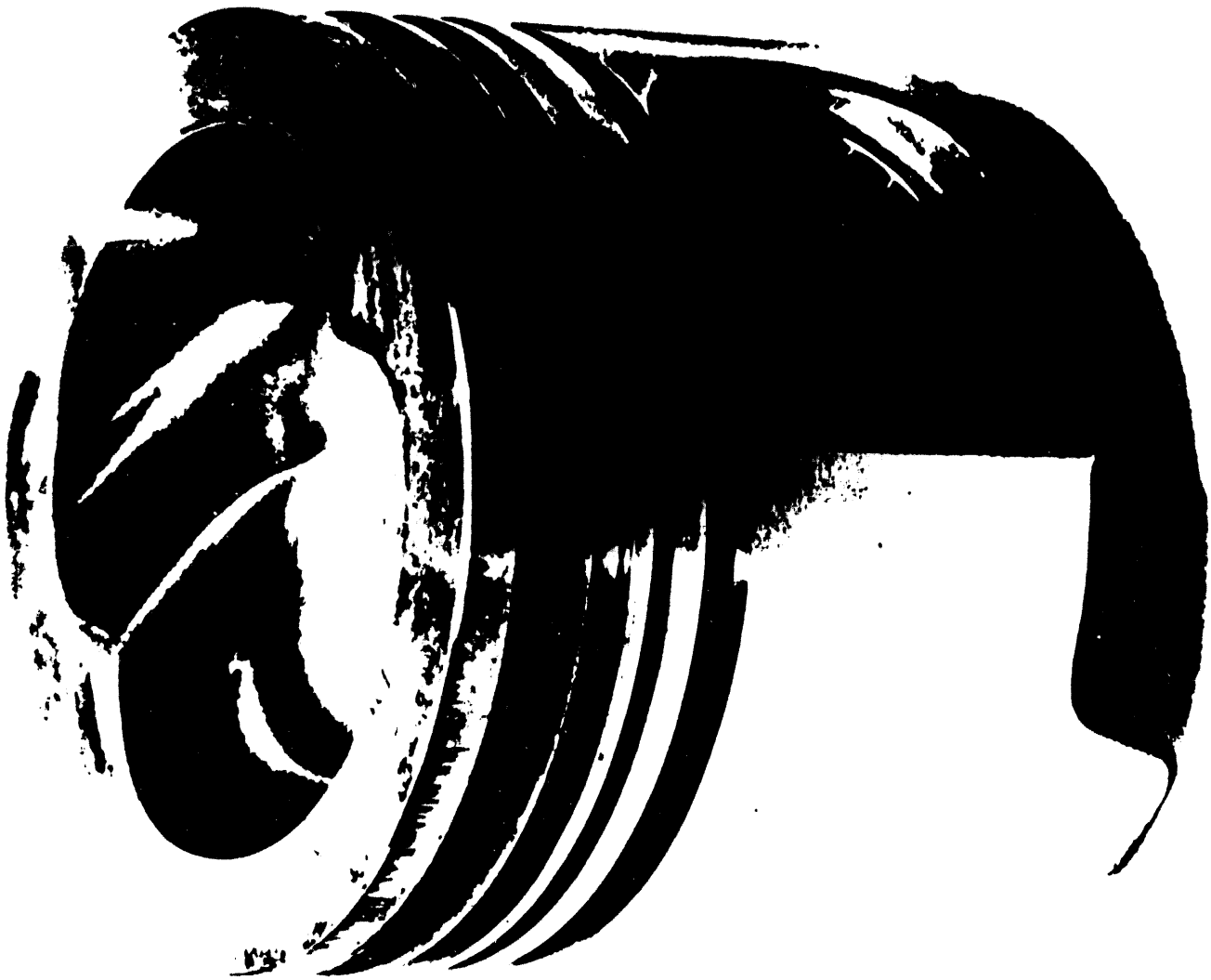
NAVISTAR CNG ENGINE PROGRAM
DESIGN MODIFICATIONS - CYLINDER HEAD

- Plug Position
- Sleeve Design
- Metal Sections
- Rocker Cover Modification
- Seat Inserts
- Use Of Current Casting

RB2_593

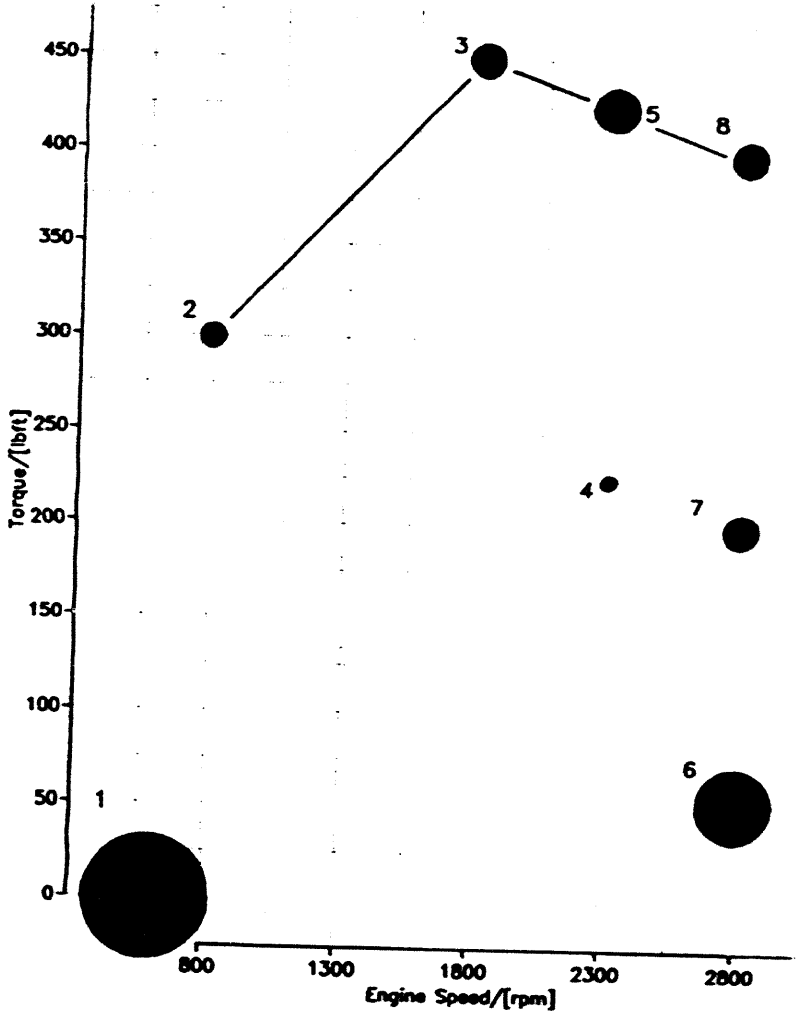
NAVISTAR CNG ENGINE PROGRAM
DESIGN MODIFICATION - PISTON

- Compression Ratio Selection
- Lost Volumes - Valve Recess
- Undercrown Thickness
- Ring Height
- Thickness Behind Ring
- Chamber Orientation/Plug Position

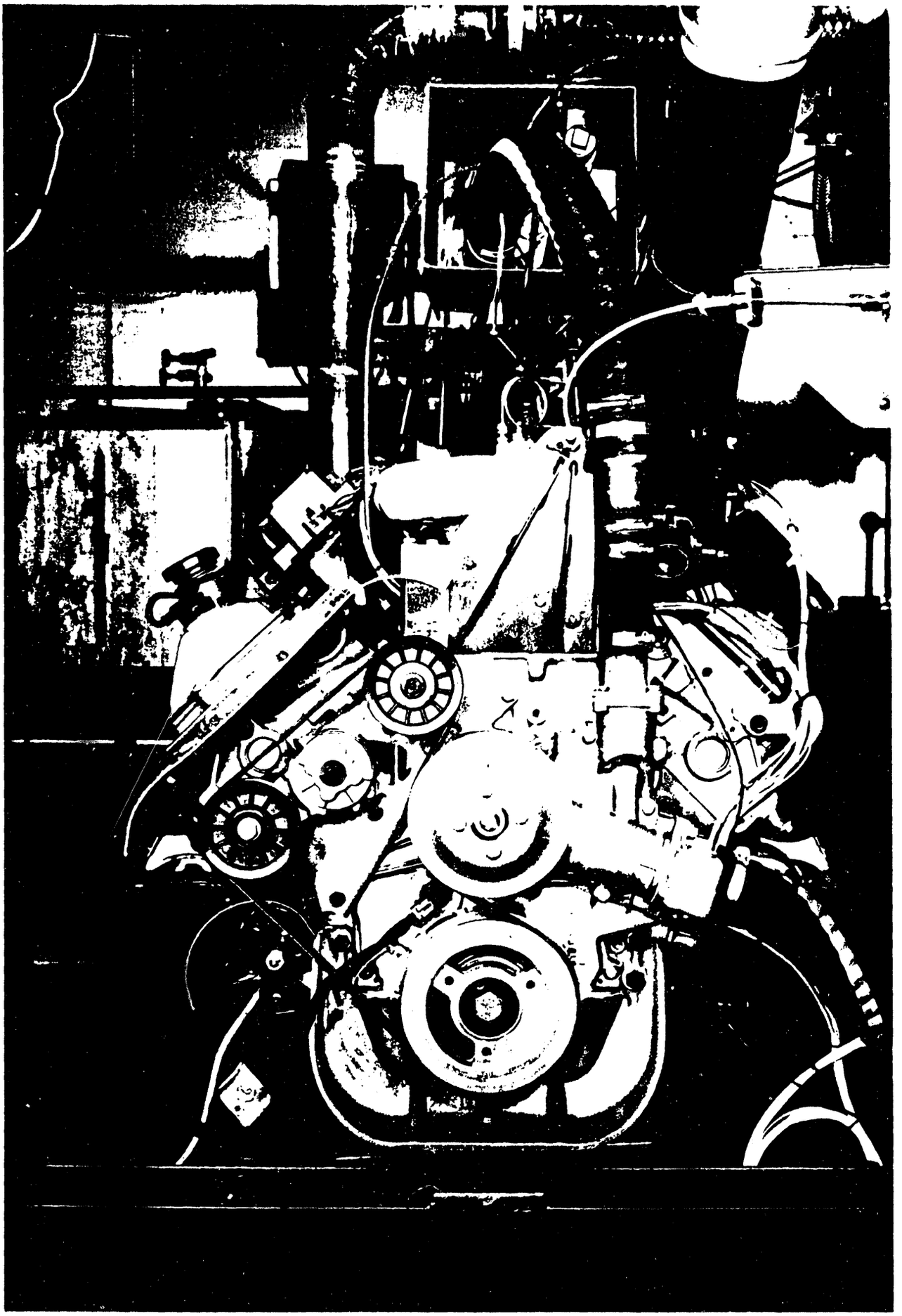


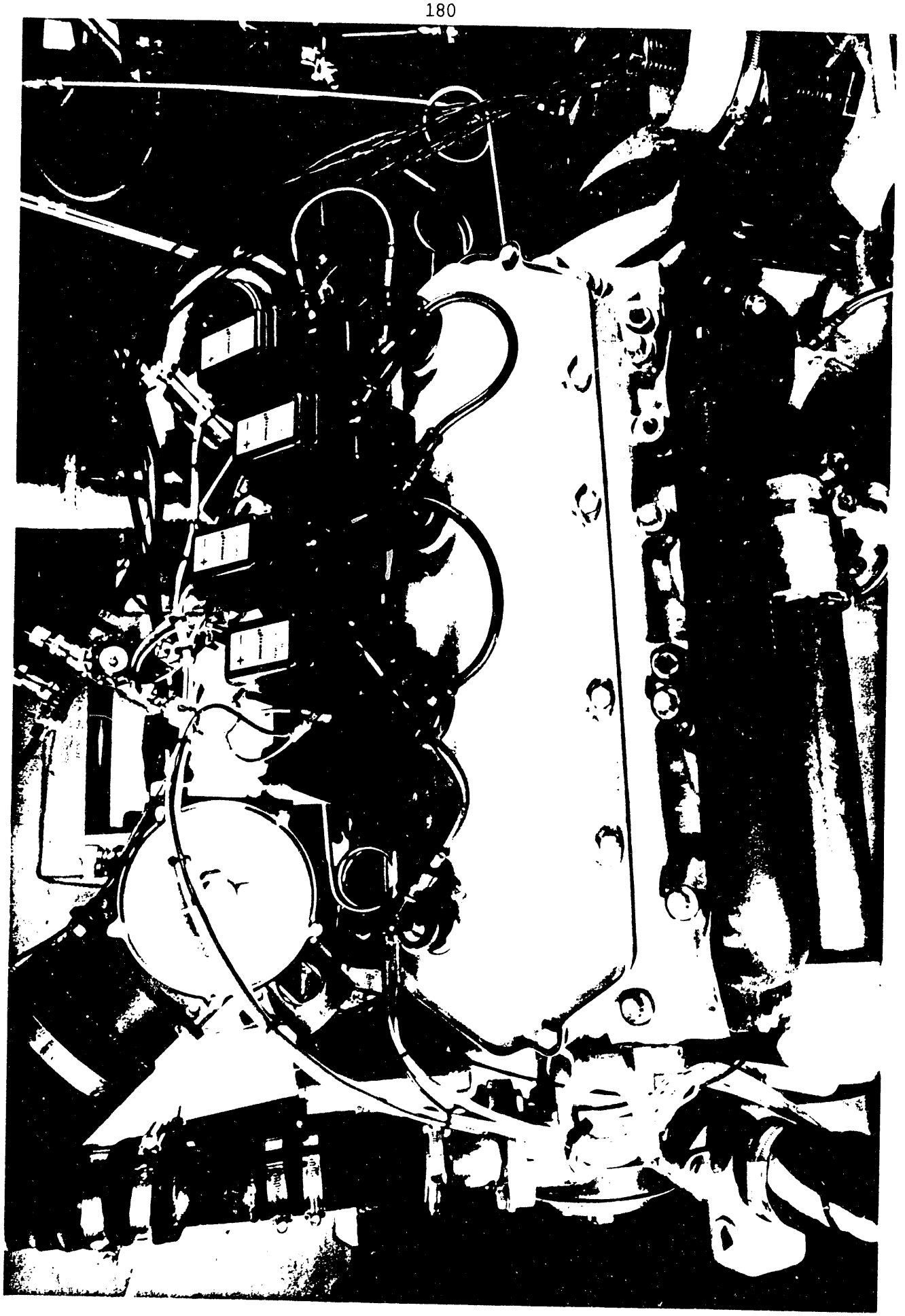
NAVISTAR CNG ENGINE PROGRAM
DESIGN MODIFICATIONS - INDUCTION SYSTEM

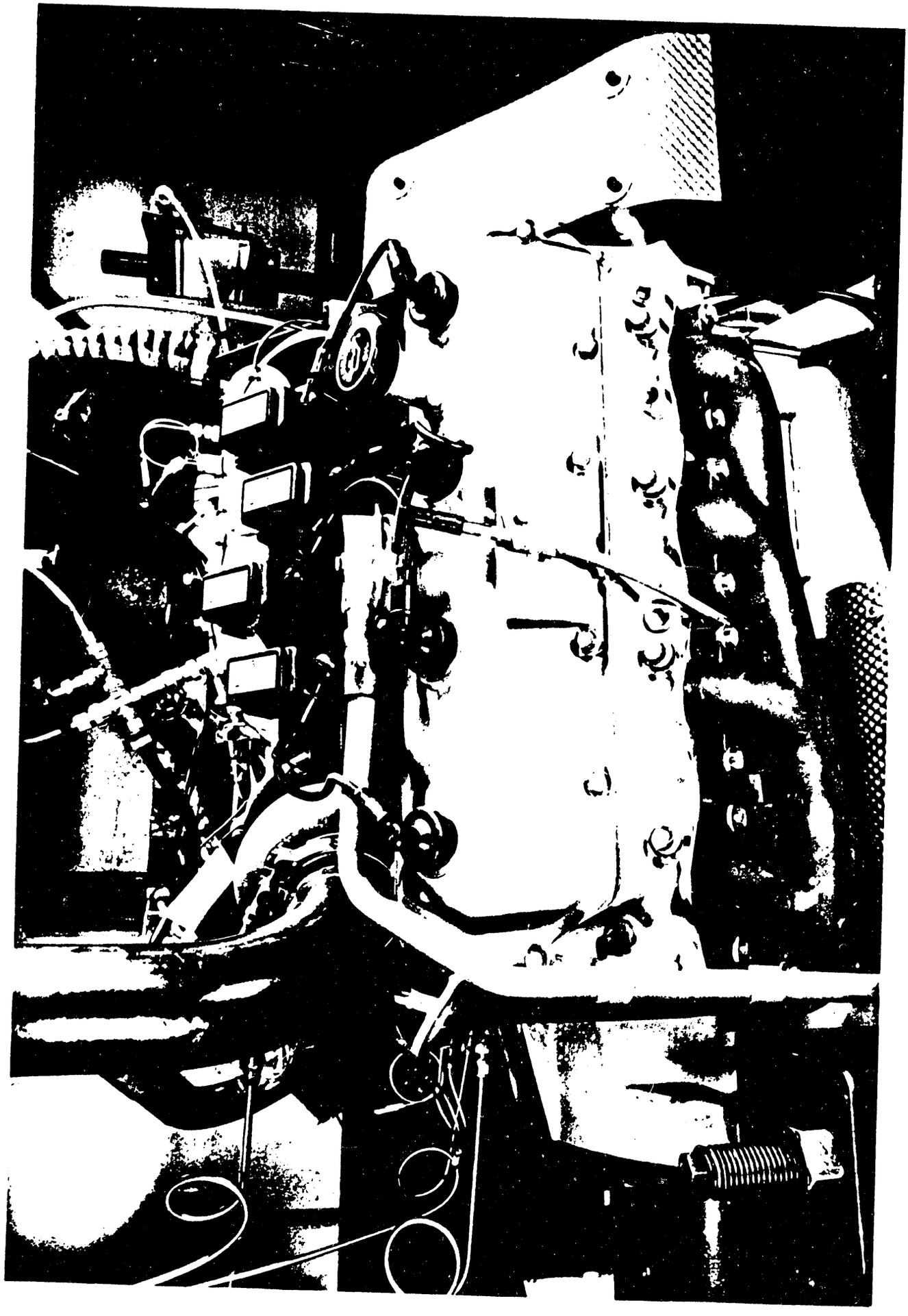
- Turbocharger Selection
- Mixer Selection
- Mixer / Throttle Relationship
- Upstream / Downstream
- Installation Constraints



8 MODE TEST POINTS



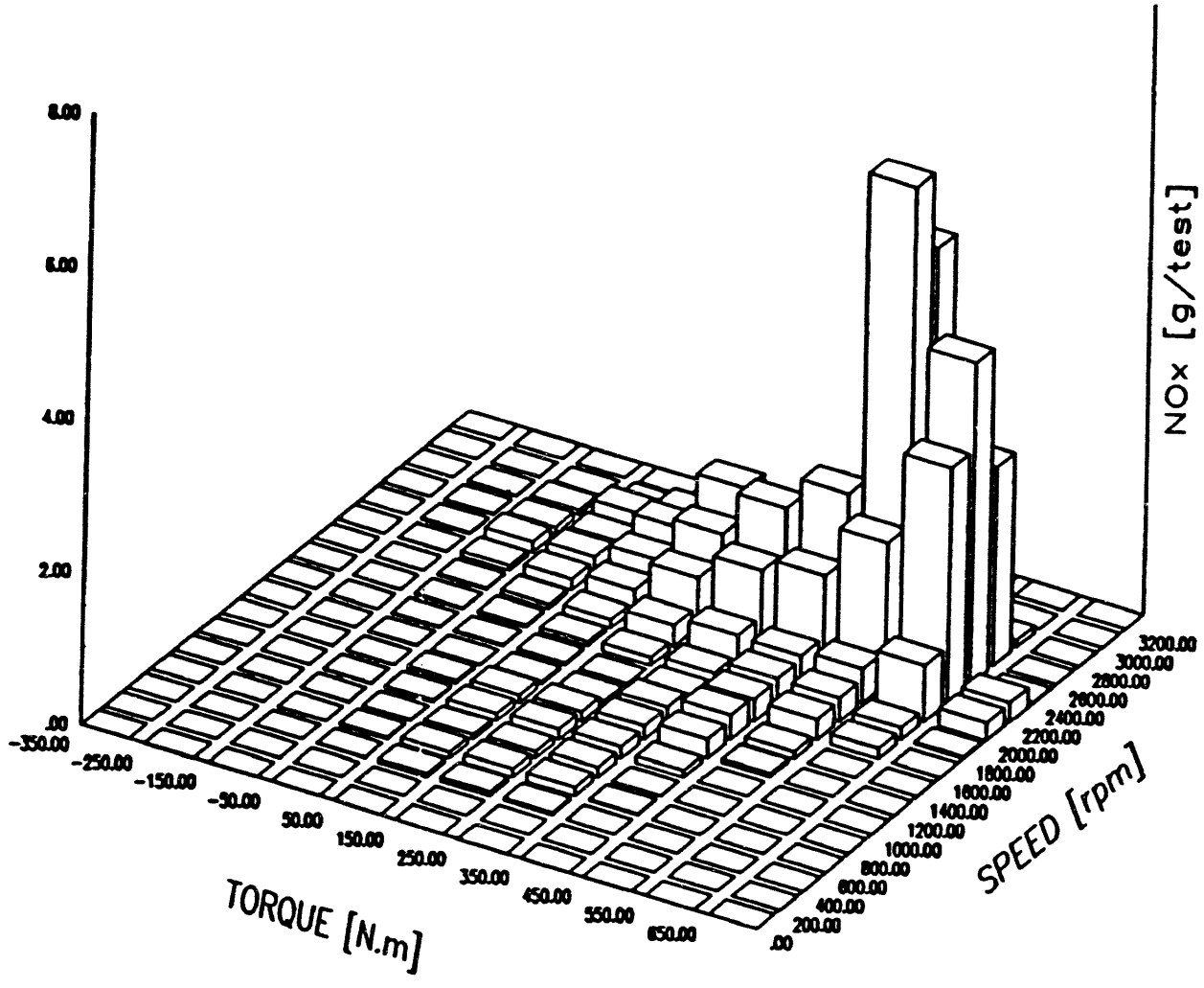




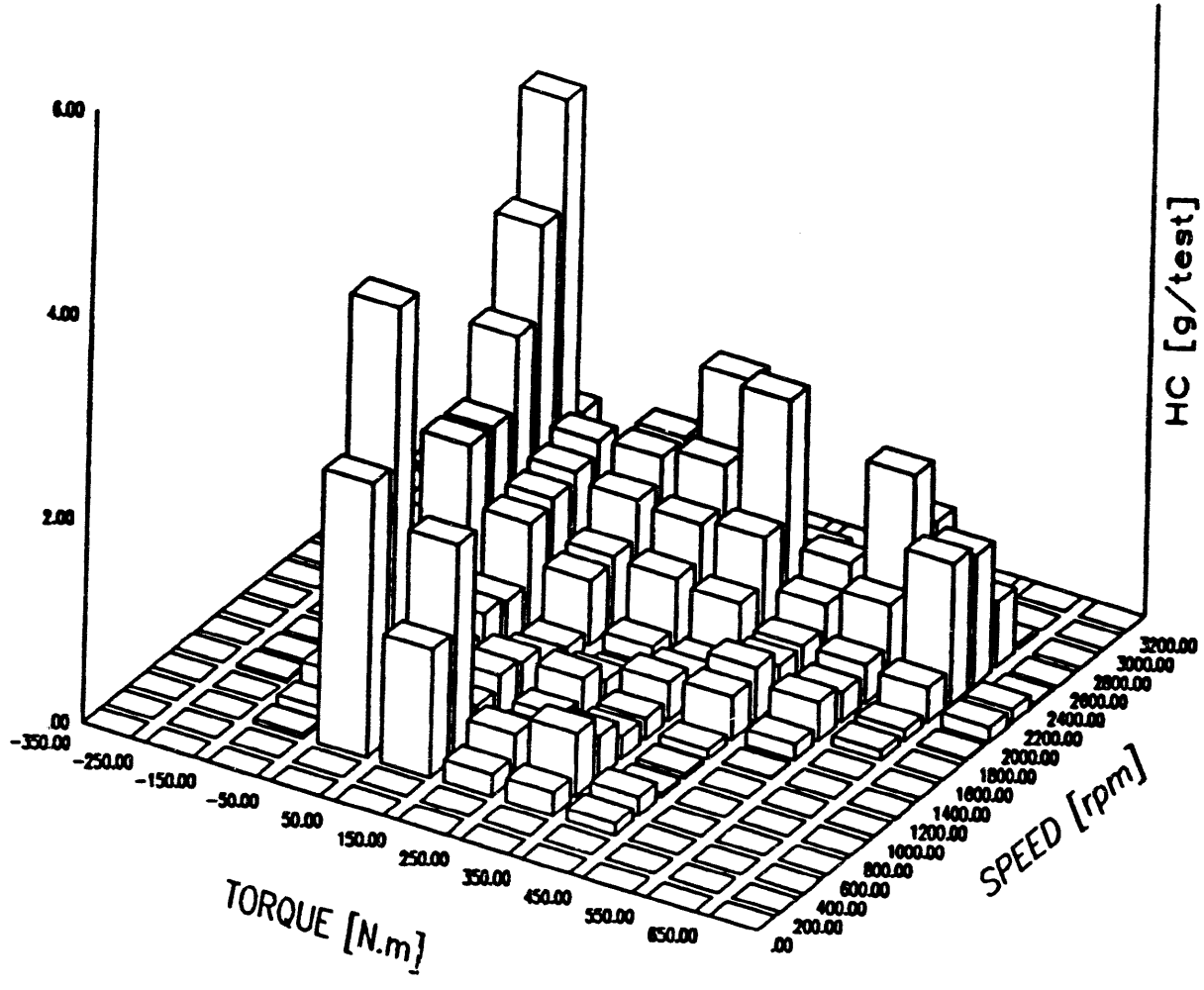
NAVISTAR CNG ENGINE PROGRAM ACHIEVEMENT

Torque Curve	Target	Achievement
Rated Power (2800 RPM)	210 BHP	210 BHP
Peak Torque (1800 RPM)	450 LB FT	450 LB FT
Low Speed (800 RPM)	240 LB FT	285 LB FT
Emissions (G/BHP-Hr) Over FTP Transient Cycle):		
NOx	4.5	2.0
CO	12.5	2.84
NMHC	1.0	0.56
PM	0.08	-
Efficiency		
Brake Thermal Efficiency (Hot Cycle)	23.0%	28.1%

RB5_593



MAP OF INTEGRATED EMISSIONS HOT START NOx



MAP OF INTEGRATED EMISSIONS HOT START HC

KEY DESIGN ISSUES OF NATURAL GAS ENGINE

- CYLINDER HEAD DESIGN
  - Cast-In Spark Plug Access
  - Cast Valve Cover (Accessibility Simplicity Of Sealing)
  - Water Jacket Optimization

- VALVE AND SEAT WEAR (ESP. EXHAUST VALVE)
  - Exhaust Seat Angle
  - Valve Face And Seat Materials

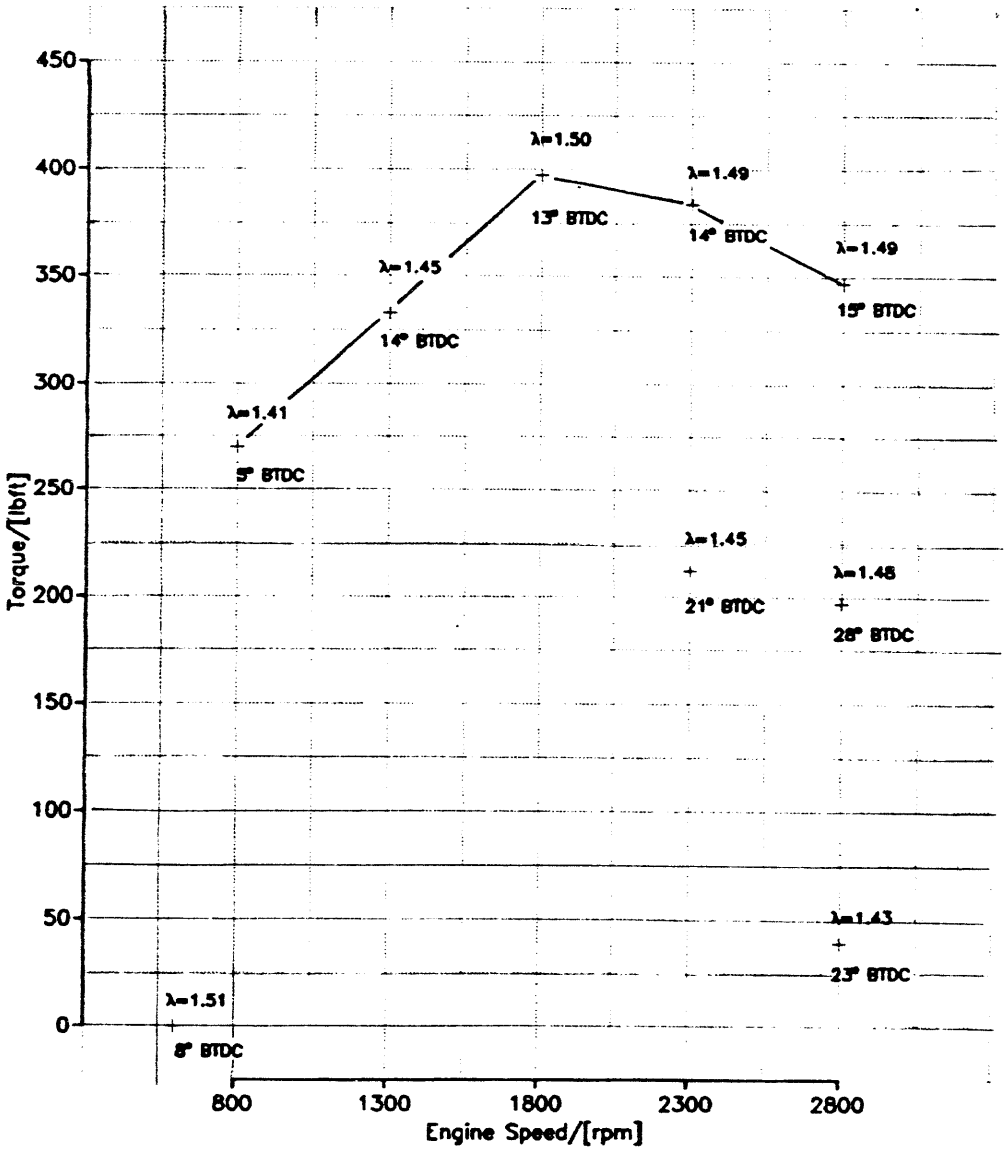
- OIL CONTROL (POWER CYLINDER ROBUST AGAINST EFFECT OF VACUUM IN INDUCTION SYSTEM)
  - Side Clearance On All Rings
  - Piston Land Diameter
  - Oil Drain Back

- COMBUSTION BOWL GEOMETRY (EFFECT OF TURBULENCE)

CALIBRATION OF VEHICLE DEMONSTRATION ENGINE

- Best Overall Solution To Satisfy:
  - Torque Shape Requirements
  - Low Emissions - NOx And HC
  - Acceptable Thermal Efficiency
  - Robustness To Ambient Temperature Effects
- Within Limits Of:
  - Mixer's Lack Of A/F Ratio Control
  - Mixer's Lack Of Temperature Compensation
  - Wastegate Actuator Hardware

RB19_593



CNG ENGINE FOR VEHICLE DEMONSTRATION IGNITION AND LAMBDA MAPS

FIELD TESTS AND VEHICLE DEMONSTRATIONS

- Objectives
  - Evaluate Engine And Fuel System In Vehicle Operation
  - Provide Workhorse For New Designs
  - Demonstrate Proof-Of-Concept To Potential Users
- One "Mule" School Bus (At Navistar)
- Five Demonstration Vehicles At Customers
  - Four Buses
  - One UPS Vehicle

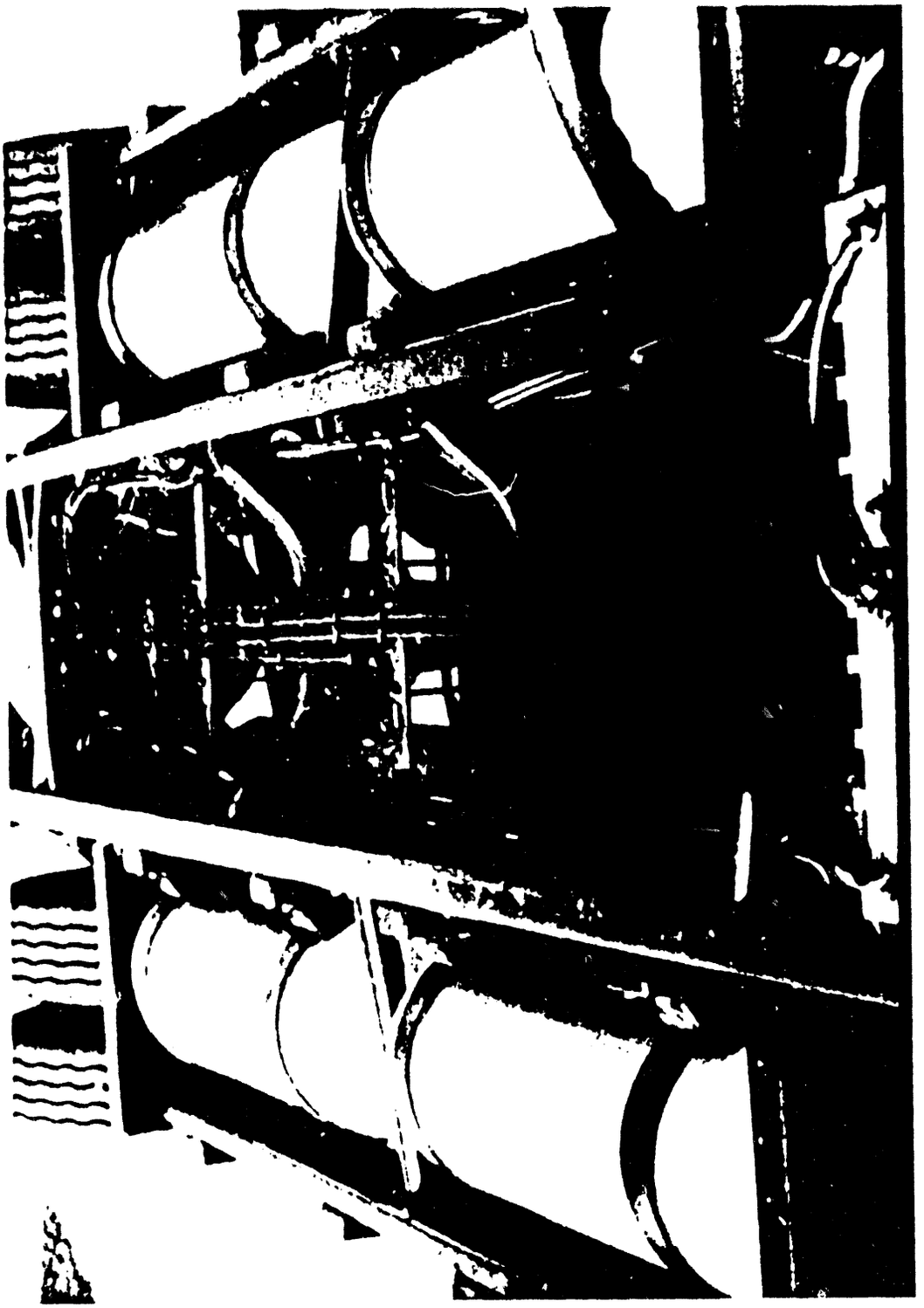
RB18_593

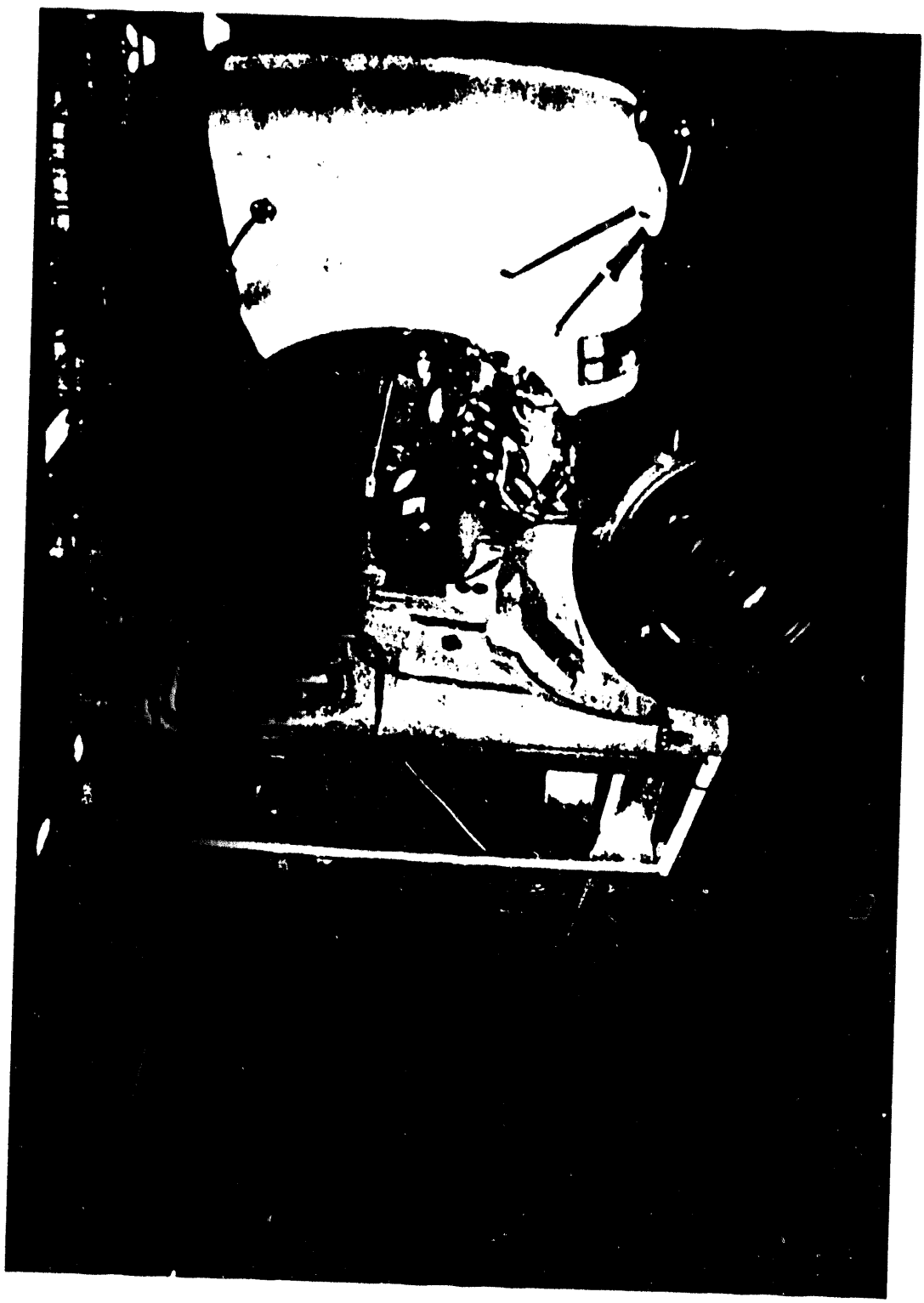
MULE VEHICLE PROGRAM

- **VEHICLE SPEC**
  - 3700 Chassis School Bus
  - Exhaust System Compatible W/CNG
  - Accelerator Cable To CNG Throttle

- **FUEL SYSTEM**
  - Four Fuel Tanks (15 X 54")
  - 5000 Ft 3@ 3000 PSI Capacity
  - 200 Mi Operating Range
  - Two Stage Pressure Regulators

- **ENGINE**
  - 7.3 CNG Proof-Of-Concept Engine
  - Impco 200 Carburetor
  - Altronic Ignition System W/ECM





MULE VEHICLE PROGRAM (Cont'd)

- **ACTIVITIES**

- Fuel Economy, Operating Range
- Driveability Performance
- Engine Cooling, Heater Performance

- Cylinders Supplier Cert. Tests
- Cylinder Mounting
- School Bus Barrier Tests

- Ignition System Tests
- Radiated Emissions
- RF Susceptibility
- Interference On Radio Systems Immunity To Water

Engine Validation

PRODUCTION DEVELOPMENT

Joint Venture Between Navistar & DDC

Time Frame: August 1993 - December 1994

Focus:

- Electronic Fuel System (Gas Valve)
- Ignition System (Automotive Inductive)
- Integrated Engine Controls (DDEC)
- Durability / Reliability Validation

Twenty Nine Engines In Laboratory And Field Tests

RB14_593

SUMMARY AND CONCLUSIONS

- A 7.3 Liter Lean Burn Natural Gas Engine Concept Was Demonstrated - For School Bus And Truck Applications - That Achieves The Same Power Output And Torque As The 7.3 Liter Diesel Engine
- The Proof-Of-Concept Has Demonstrated Emission Levels Lower Than Initial Targets On All Major Pollutants, And Compliance With Emission Standards of 1994 - 1995 (US & California)
- Energy Efficiency Of The Concept Engine Has Exceeded Initial Targets; It Is Only About 12% Inferior To Diesel Efficiency

SUMMARY AND CONCLUSIONS (Cont'd)

- Upcoming Vehicle Demonstrations Will Validate The Proof-Of-Concept And The Key Design Features Such As:
  - Cylinder Head
  - Valve Train Design And Durability
  - Power Cylinder Design For Oil Control
  - Air Management, Induction System
  - Vehicle Fuel System

- Production Development Of The 7.3L Engine Will Focus On:
  - Fuel System Development
  - Ignition System Development
  - Integrated Engine Controls

To Utilize The Latest Technology Achievements In Gaseous Fuel Systems And Electronic Controls

RB16_593

SUMMARY AND CONCLUSIONS (Cont'd)

- Market Introduction Of The New Engine Is 1995
- The 7.3 Liter Natural Gas Engine Is A Viable Alternative For Advanced Mobile Applications Where Gaseous Fuels Are The Preferred Choice (Non Attainment Areas, Urban Fleets, School Buses, Etc...)
- Future Developments May Be Applied To This Engine To Reduce Emissions Even More, In Compliance With Evolving Standards

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

NATURAL GAS IN VEHICULAR APPLICATIONS - STATUS OF DEVELOPMENT AT NAVISTAR

R.A. Baranescu, Navistar International Corporation

Q. Eric Milkins, NGV-Australia: We have had similar experience with lean burn engines with a range of 1.5 to 2.0 for lambda values. Would you comment on air/fuel ratios used in your work?

A. We started at a lambda value of 1.5, but have gone as high as 1.7 which was the maximum value limited by hydrocarbon emissions. With an oxidation catalyst we could go to higher values of lambda.

Q. Mostafa Kamel, Cummins Engine Co.: Can you tell us why the capacitive discharge ignition system was selected?

A. This engine was developed for the lowest possible cost, and the ignition system selected was the obvious choice for that objective.

Q. Mehboob Sumar, ORTECH International: Was there any pre-ignition or deterioration at high speed?

A. So far, no problems have been experienced.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

UPDATE ON LIGHT DUTY ENGINES PANEL DISCUSSION

Panel Moderator: Ron Bright

GENERAL MOTORS ALTERNATIVE FUEL PRODUCTS

J. Christie
General Motors of Canada

(Other presentations made during this Panel Discussion are unavailable)

GENERAL MOTORS ALTERNATIVE FUEL PRODUCTS

by

JOHN M. CHRISTIE

at

1993 WINDSOR WORKSHOP, TORONTO, ONTARIO

JUNE 14, 1993

GM
ALTERNATIVE FUEL VEHICLES

JMCLOGO1

HISTORY OF GM ALTERNATIVE FUEL VEHICLE PRODUCTION

FUEL	TIME PERIOD	PRODUCTS	VOLUME
PROPANE/LPG	1984/85	PICKUPS & VANS (CANADA ONLY)	<300
METHANOL/ETHANOL	1991/93	CHEVROLET LUMINA VFV	2100
ETHANOL E20+	THRU 1993	GM DO BRASIL CARS & TRUCKS	250,000
NATURAL GAS	1992/93	GMC/CHEVROLET 3/4 TON PICKUPS	2300
ELECTRICITY	---	GM OF EUROPE BEDFORD VANS	70
ELECTRICITY	1991	GM/VEHMA G-VAN	

JMC93:B:193-46.06/JUNE93

JMCLOGO1

GM ALTERNATIVE FUEL VEHICLES

WE HAVE LEARNED A LOT ABOUT:

ALCOHOL VFV'S:

- FUEL SENSORS & INJECTORS
- EVAPORATIVE EMISSION CONTROLS
- HOT RE-START
- COLD START
- MATERIAL COMPATIBILITY
- FUEL PUMP
- CONVENTIONAL TAILPIPE EMISSIONS

GASEOUS FUEL VEHICLES:

- COMPRESSION RATIO & POWER
- CNG FUEL STORAGE
- AIR/FUEL DISTRIBUTION
- COLD START
- FUEL PRESSURE REGULATOR
- TAILPIPE EMISSIONS

THERE IS MORE TO LEARN ABOUT:

ALCOHOL FUEL VFV'S

- ALDEHYDE CONTROL
- ULTRA - LOW EMISSIONS
- SPECIFIC CATALYSTS
- ENHANCED EVAPORATIVE EMISSION STANDARDS
- **OBDII** - DIAGNOSTICS
- HIGH MILEAGE COMPONENT DURABILITY
- HANDLING LOW QUALITY FUEL
- LOWER COST SYSTEMS

GASEOUS FUEL VEHICLES

- OBDII - DIAGNOSTICS
- HIGH MILEAGE COMPONENT DURABILITY
- **THC** CONTROL
- FUEL STORAGE
- LOWER COST SYSTEMS

JMCX3:B:193-46:06/JUNE93

JMCLOBO1

GM ALTERNATIVE FUEL VEHICLES

WHERE THE DEMAND WILL BE, 2000 A.D.:

EPACT

- FEDERAL & STATE FLEETS
- FUEL PROVIDERS
- PRIVATE FLEETS

PLUS

FREE MARKET

- STATE/MUNICIPAL FLEETS
- PRIVATE FLEETS
- INDIVIDUALS

WHY THEY WILL BUY:

ALCOHOL FUEL VEHICLES

- MANDATED & LOW FUEL USERS
- MANDATED & LOW BID
- ADVOCATES/FUEL PROVIDERS

GASEOUS FUEL VEHICLES

- MANDATED & HIGH FUEL USERS
- MANDATED NGV PURCHASES
- FREE MARKET HIGH FUEL USERS
- ADVOCATES/FUEL PROVIDERS

ELECTRIC VEHICLES

- OE MANDATED SALES (2 % CALIFORNIA)

JMCI3:B:193-46:08JUNE93

JMCL0801

GM ALTERNATIVE FUEL VEHICLES

ROLL-OUT = PRODUCTS + TIMING+ VOLUMES + WHERE

	ALCOHOL FUEL VEHICLES	GASEOUS FUEL VEHICLES	ELECTRIC VEHICLES
PRODUCTS	COMPACT CARS/TRUCKS	FULL SIZE CARS/TRUCKS CURRENT CONVERSION PRODUCTS	COMMUTER CAR AND/OR MINIVAN
TIMING	1998 - 2000 AD	NOW	1998
VOLUMES	N/A	N/A	2% OF OE CALIFORNIA SALES
WHERE	US WIDE	US WIDE & REGIONAL	CALIFORNIA

JMCR3:B:193-46:08JUNE93

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GM ALTERNATIVE FUEL VEHICLES

BUSINESS CASE = CONSERVATIVE ESTIMATE + OTHER SUPPORT

"OTHER SUPPORT" HAS SIGNIFICANT UPSIDE POTENTIAL:

- ***CAFE*** *CREDIT*
- *PUBLIC RELATIONS*
- *"HALO" SALES*
- *IMPROVE GASOLINE*
- ***EPACT*** *FUEL USE OBJECTIVE*
- *COMPETITIVE STRATEGIES*
- *MARKETS OUTSIDE USA*
- *FUEL PROVIDER MARKETING*

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GM ALTERNATIVE FUEL VEHICLES

JMCLOSO1

WHAT COULD/WILL HAPPEN:

1. OE'S COULD ABANDON METHANOL/ETHANOL PROGRAMS

- FUEL COST NOT ATTRACTIVE
- FRAGMENTED MARKET
- GOVERNMENT POLICY DRIVEN; NO CUSTOMER DRIVERS
- FUEL INFRASTRUCTURE INADEQUATE
- FUEL QUALITY NOT ADDRESSED
- EXPENSIVE **O.E.** DEVELOPMENT PROGRAMS
- CHALLENGING EMISSION STANDARDS: **OBDII & EVAP**

BIG FACTORS: GOVERNMENT POLICY, FUEL COST, FUEL QUALITY, FUEL AVAILABILITY

JMC#3:B:193-46:08JUNE93

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GM ALTERNATIVE FUEL VEHICLES

WHAT COULD/WILL HAPPEN (Cont'd):

2. OE'S WILL BE IN THE GASEOUS FUEL MARKET WILLINGLY OR UNWILLINGLY

- TWO WAYS
  - AFTERMARKET CONVERSIONS
  - O.E. MONO-FUEL/BI-FUEL PROGRAMS

- FREEMARKET CUSTOMER DRIVEN - LOW FUEL COST & ENVIRONMENTAL BENEFITS
- STEADY REGIONAL GROWTH
- HOME REFUELLING APPLIANCE
- PRO-ACTIVE GOVERNMENT SUPPORT - FEDERAL/STATE

BIG FACTORS: PRODUCT COSTS; FUEL QUALITY; FUEL AVAILABILITY

JMCK13:B:193-46:06JUNE93

JMCLOB01

GM ALTERNATIVE FUEL VEHICLES

WHAT NEEDS TO BE DONE:

1. **MOVE ALTERNATIVE FUEL VEHICLES OFF THE ENVIRONMENTAL AGENDA**
   - SMALL VOLUME; SMALL BENEFIT
   - OTHER MORE EFFECTIVE STRATEGIES
2. **IMPLEMENT AN EFFECTIVE COMMERCIALIZATION STRATEGY**
   - DRIVEN BY ENERGY SELF SUFFICIENCY & ECONOMICS
   - UTILIZE CUSTOMER INFLUENCES
     - WHAT MAKES SENSE TO CUSTOMER, MAKES SENSE UPSTREAM
     - CUSTOMERS NEED TO UNDERSTAND AND BELIEVE

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

UPDATE DATE ON LIGHT DUTY ENGINES - PANEL PRESENTATIONS GENERAL MOTORS ALTERNATIVE FUEL PRODUCTS

J. Christie, General Motors of Canada

Q. Anonymous: Is there a reduction in purchases of alternative fuel vehicles after their introduction?

A. Yes, the initial purchase rates are the highest right after the production run. It is a matter of developing the best product for customer acceptance.

Q. Anonymous: What has been the experience on warranty costs for propane and natural gas conversions?

A. We analyzed data on 10,000 vehicles over the last 10 years in Canada. The significant finding was that complaints were related more to the installation rather than to the hardware.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

HIGHLIGHTS OF CHRYSLER'S ALTERNATIVE FUEL PROGRAMS

J.W. Lanigan, Chrysler Canada Ltd.

(Presentation unavailable at time of printing)

Q. Alex Lawson, Alex Lawson Associates: I didn't hear hybrid electric vehicles mentioned in your talk.

A. We are not ignoring that possibility. The program will be emphasized when appropriate for the consumer.

Comment: Ron Bright, Ford Motor Co. - Canada: The University of Alberta was first in competition with 30 universities and did an outstanding job of vehicle modification.

Q. Bernie James, Energy, Mines & Resources Canada: What percentage of power do you expect from regenerative braking systems?

A. It depends on the duty cycle, but in current tests we get on the order of 5 to 10 percent.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

STRATEGIES TOWARD EXPANDING NGV PRODUCTION
T.W. Rogers, Cardinal Automotive Inc.

(Presentation unavailable at time of printing)

Q. Chandra Prakash, Environment Canada: How many vehicles have you converted to natural gas?

A. We do more conversions to fuels other than natural gas. The demand for natural gas conversions has been relatively low, and we have done groups of 1 to 4 vehicles at a time.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

AFTERMARKET NG CONVERSIONS OR OEM PRODUCTS - STRATEGIC OPTIONS AND I IMPACTS

B. Wilson, Colorado State University

(Presentation unavailable at time of printing)

Q. Anonymous: Various conversions are now available with closed loop controls integrated with hardware. Would you comment on these?

A. There are five types of systems being used: Fully mechanical, mechanical with closed loop oxygen feedback, fully electronic add-ons, translators which work with OEM computers, and OEM electronic systems. The second of those, if properly installed, gives good air/fuel ratio control at steady state but does not handle transients well.