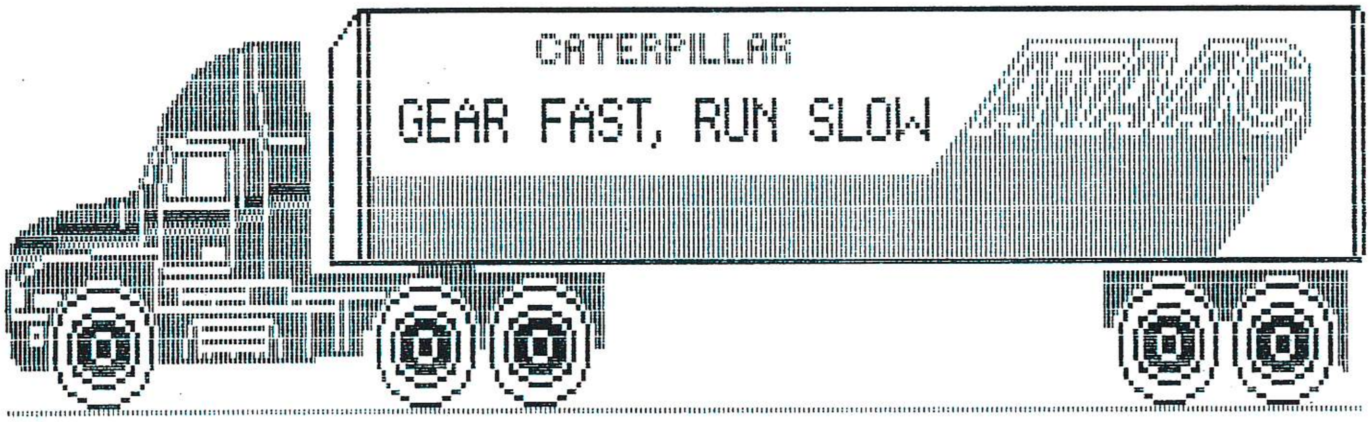
Truck Performance Analysis

BY CATERPILLAR



Presented by : Warren Sargent

Engine Manager
Gough Gough and Hamer Ltd

NZ Caterpillar Dealers

TRUCK PERFORMANCE ANALYSIS

(1) What is Truck Performance Analysis (TPA)

TPA is the analysis (via copmputer) of the theoretical performance of an engine, drive train, axle and body configuration to ensure the truck is correctly analyised to meet its intended application

(2) Why is an engine manufacturer involved in analysis.

Todays truck engine requirement is not just the demand for so many horesepower at a particular engine rpm but rather for a more specialised engine designed to meet a specific requirement at the best possible fuel economy.
To enable the engine to perform to these parameters with the use of the TPA we are able to accuratly estimate the performance and economy of the engine.

(3) What advantage is a TPA.

By changing input variables (Engine (hp & rpm), transmission, tyres, axle ratios etc) changes in performance can be tabulated, and the best match of componants selected to accomplish the owners objectives. A typical objective would be a compromise between acceptable startability, top geared speed, and reserve gradeability at 55mph.

Truck performance analysis provides you with a rapid check of checking anticipated characteristics of a vehicle and can lead to user satisfaction rather than misapplication problems after the truck enters service. It is important to recognise this is not a guarentee of actual truck performance to the user. The output serves only as a guide as to what may be anticipated.

CATERPILLAR

07-27-198?

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HEAVY VEHICLE
SEMINAR
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TOWN HALL
CHRISTCHURCH

PREPARED BY: WARREN SARGENT

TRUCK PERFORMANCE ANALYSIS

** Run ID: 9**

In Imp. Gallons

*** ENGINE: 3406B ATAAC M , CODE (TM7711),

RATED POWER BHP	RATED SPEED RPM	PEAK TORQUE FT-LB	PEAK TORQUE RPM	FAN LOSS HP	ACCESSORY LOSS HP	ENGINE INERTIA FT-LB-SEC2	ENGINE DISP CU IN	LOAD STARTING FT-LBS
425	1800	1450	1200	0	11	2.3	893	644.

*** TRANSMISSION: FULLER RTO-14613

*** REAR AXLE:
NO OF DRIVE AXLES: 2
TOTAL NO OF AXLES: 7
RATIO(S): 3.90

*** TRUCK TYPE: TR/Double Van
SIDE: Smooth
TOP: Closed
DUTY CYCLE: Line Haul
WIDTH: 8 FT.
HEIGHT: 13.5 FT.
GVW/GCW: 98560 LBS

COEFFICIENT OF DRAG FOR BASIC CONFIGURATION: .77
MODIFIED COEFFICIENT OF DRAG: .65

*** TIRES: 11.00X22.5 R
TIRE TYPE: Radial
REV/MILE: 497

*** COURSE SURFACE: Asphalt
ROLLING RESISTANCE 13.3 LBS/TON
ENVIRONMENTAL CONDITIONS:
ZERO WIND VELOCITY, 77 DEG F., 500 FT ALTITUDE.

Engine Files Last Updated : Jan 1,1989

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PREPARED BY: WARREN SARGENT

TRUCK PERFORMANCE ANALYSIS

** Run ID: 9** In Imp. Gallons

ENGINE: 3406B ATAAC M	RTD POWER: 425 HP	RTD SPD: 1800 RPM
PK.TORQ: 1450 FT-LB	P-T SPD: 1200 RPM	TRANS:FULLER RTO-14613
AXLE:	DRIVE AXLES: 2	TOTAL AXLES: 7
RATIO(S): 3.90	TRUCK:TR/Double Van	WIDTH: 8 FT.
HEIGHT: 13.5	GVW/GCW: 98560 LBS	DRAG COEF: .65
TIRES: 11.00X22.5 R	REV/MI: 497	ROAD SURFACE: Asphalt
RLG RES: 13.3 LBS/TON	ACC HP: 11	CRUISE SPEED: 60

SUMMARY OF VEHICLE PERFORMANCE PARAMETERS

MAIN TRAN GEAR	AUX TRAN NO.	TRANS GEAR RATIO	TOTAL GEAR RATIO	MPH AT RATED RPM	RPM AFTER SHIFT
1	0	12.56	48.98	4.4	0
2	0	8.32	32.45	6.7	1192
3	0	6.18	24.10	9.0	1337
4	0	4.54	17.71	12.3	1322
5	0	3.38	13.18	16.5	1340
6	0	2.46	9.59	22.6	1310
7	0	2.15	8.39	25.9	1573
8	0	1.83	7.14	30.4	1532
9	0	1.60	6.24	34.8	1574
10	0	1.34	5.23	41.6	1508
11	0	1.17	4.56	47.6	1572
12	0	1.00	3.90	55.7	1538
13	0	0.87	3.39	64.0	1566

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TRUCK PERFORMANCE ANALYSIS

** Run ID: 9** In Imp. Gallons

ENGINE: 3406B ATAAC M	RTD POWER: 425 HP	RTD SPD: 1800 RPM
PK.TORQ: 1450 FT-LB	P-T SPD: 1200 RPM	TRANS:FULLER RTO-14613
AXLE:	DRIVE AXLES: 2	TOTAL AXLES: 7
RATIO(S): 3.90	TRUCK:TR/Double Van	WIDTH: 8 FT.
HEIGHT: 13.5	GVW/GCW: 98560 LBS	DRAG COEF: .65
TIRES: 11.00X22.5 R	REV/MI: 497	ROAD SURFACE: Asphalt
RLG RES: 13.3 LBS/TON	ACC HP: 11	CRUISE SPEED: 60

SUMMARY OF VEHICLE PERFORMANCE PARAMETERS

MAIN TRAN GEAR NO.	AUX TRAN GEAR NO.	DRIVE TRAIN HP LOSS	AIR RESIST HP LOSS	ROLL. RES. HP LOSS	GROSS DEMAND HP	PERCENT OF RATED WHEEL HP AT SHIFT	% GRADE CAP. AT PEAK TORQ RPM	MAX STARTING GRADE
1	0	74.7	0.0	7.8	93.5	0.0	36.5	12.7
2	0	64.4	0.1	11.7	87.2	79.4	23.8	5.4
3	0	57.3	0.3	15.8	84.4	87.8	17.7	0.8
4	0	52.0	0.8	21.5	85.2	87.1	12.9	0.0
5	0	48.2	1.9	28.9	89.9	87.9	9.5	0.0
6	0	45.1	4.9	39.7	100.7	86.5	6.7	0.0
7	0	44.1	7.4	45.4	107.9	96.4	5.8	0.0
8	0	43.1	12.0	53.3	119.4	95.4	4.8	0.0
9	0	42.3	18.0	61.0	132.3	96.4	4.1	0.0
10	0	41.5	30.6	72.8	155.8	94.7	3.3	0.0
11	0	41.2	45.9	83.4	181.5	96.4	2.7	0.0
12	0	41.2	73.5	97.6	223.3	95.6	2.2	0.0
13	0	41.2	111.7	112.1	276.0	96.2	1.7	0.0

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TRUCK PERFORMANCE ANALYSIS

** Run ID: 9**

In Imp. Gallons

ENGINE:	3406B ATAAC M	RTD POWER:	425 HP	RTD SPD:	1800 RPM
PK.TORQ:	1450 FT-LB	P-T SPD:	1200 RPM	TRANS:	FULLER RTO-14613
AXLE:		DRIVE AXLES:	2	TOTAL AXLES:	7
RATIO(S):	3.90	TRUCK:	TR/Double Van	WIDTH:	8 FT.
HEIGHT:	13.5	GVW/GCW:	98560 LBS	DRAG COEF:	.65
TIRES:	11.00X22.5 R	REV/MI:	497	ROAD SURFACE:	Asphalt
RLG RES:	13.3 LBS/TON	ACC HP:	11	CRUISE SPEED:	60

TOP SPEED IN HIGHEST GEAR ON ZERO PERCENT GRADE

GCW LB	REAR AXLE RATIO	TRANS GEAR RATIO	TOTAL GEAR RATIO	MPH TOP SPEED	ENGINE SPEED RPM
98560	3.90	0.87	3.39	66.6	1871

ENGINE ACCESS HP LOSS	DRIVE TRAIN HP LOSS	AIR RESIST HP LOSS	ROLLING RESIST HP LOSS	GROSS DEMAND HP
11.4	34.3	125.5	116.6	287.8

Engine Files Last Updated : Jan 1,1989

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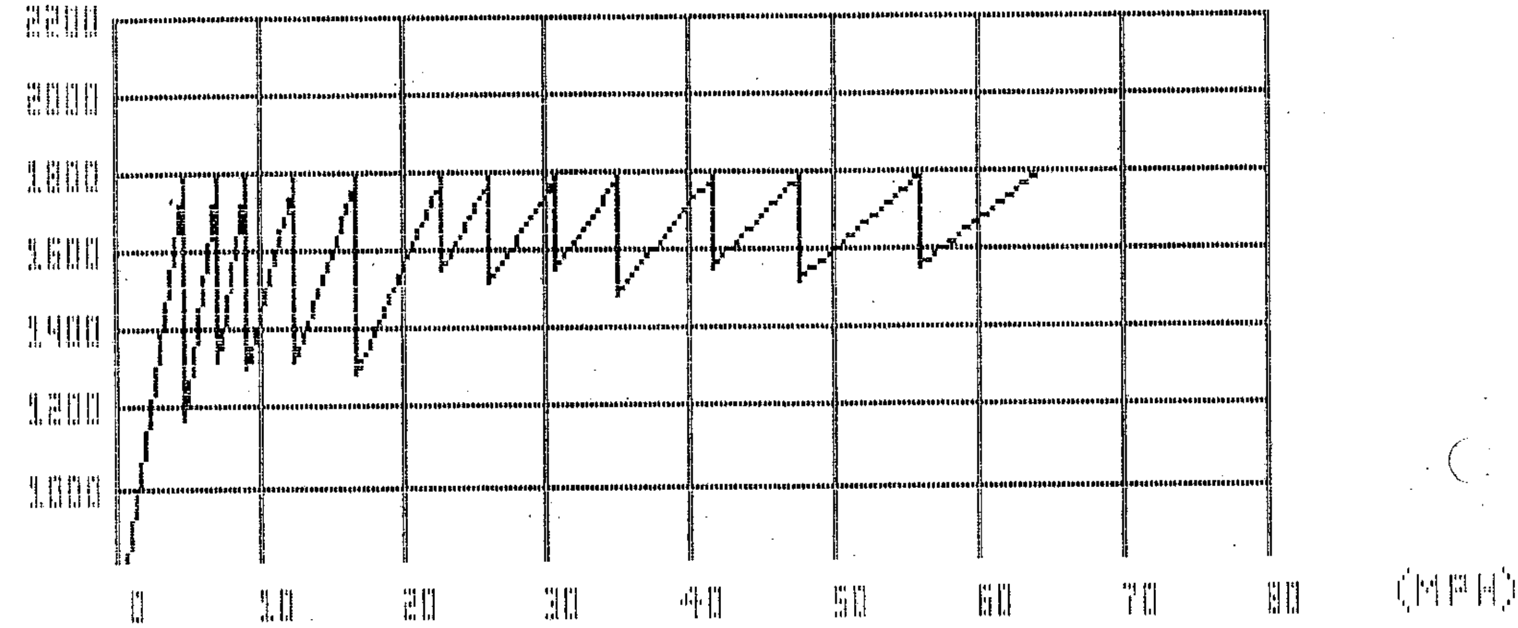
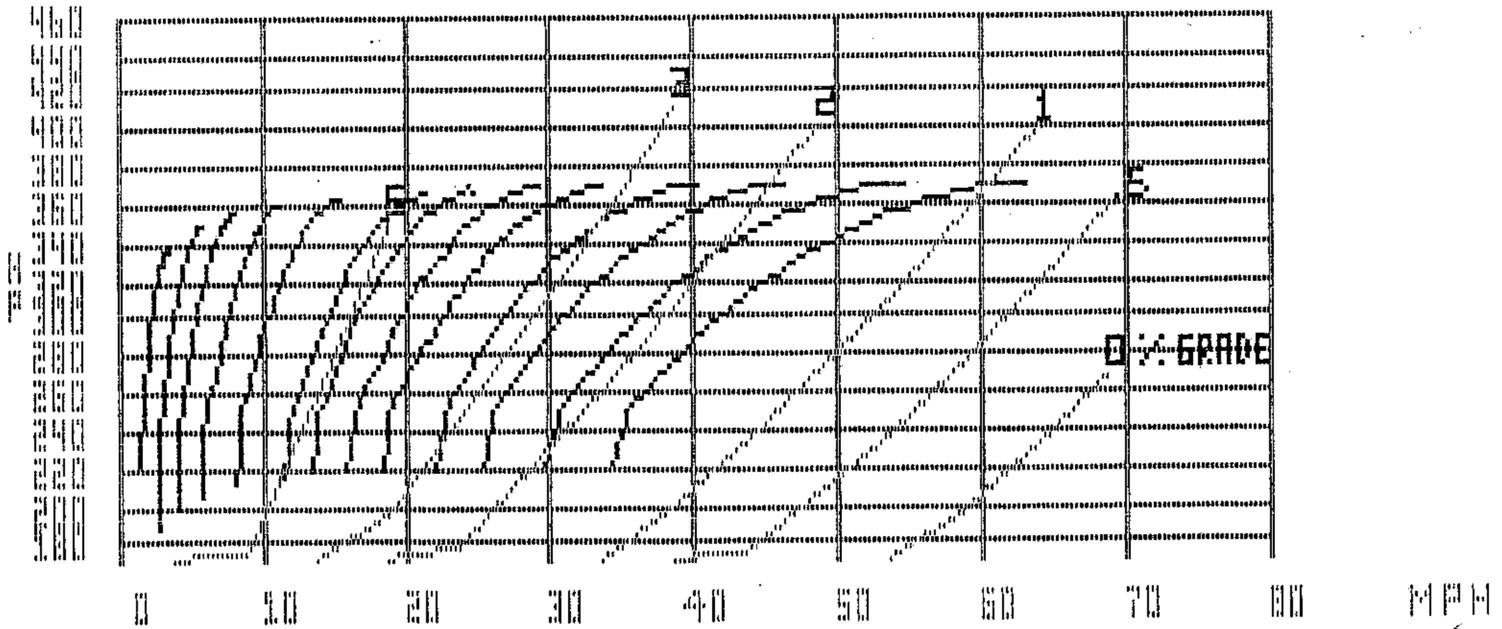
PREPARED BY: WARREN SARGENT

Eng: 3406B ATAAC M 425 hp @1800 RPM
Trans: RTO-14613 Axle: 3.9:1
Tires: 11.00X22.5 GVW/GCW:98560





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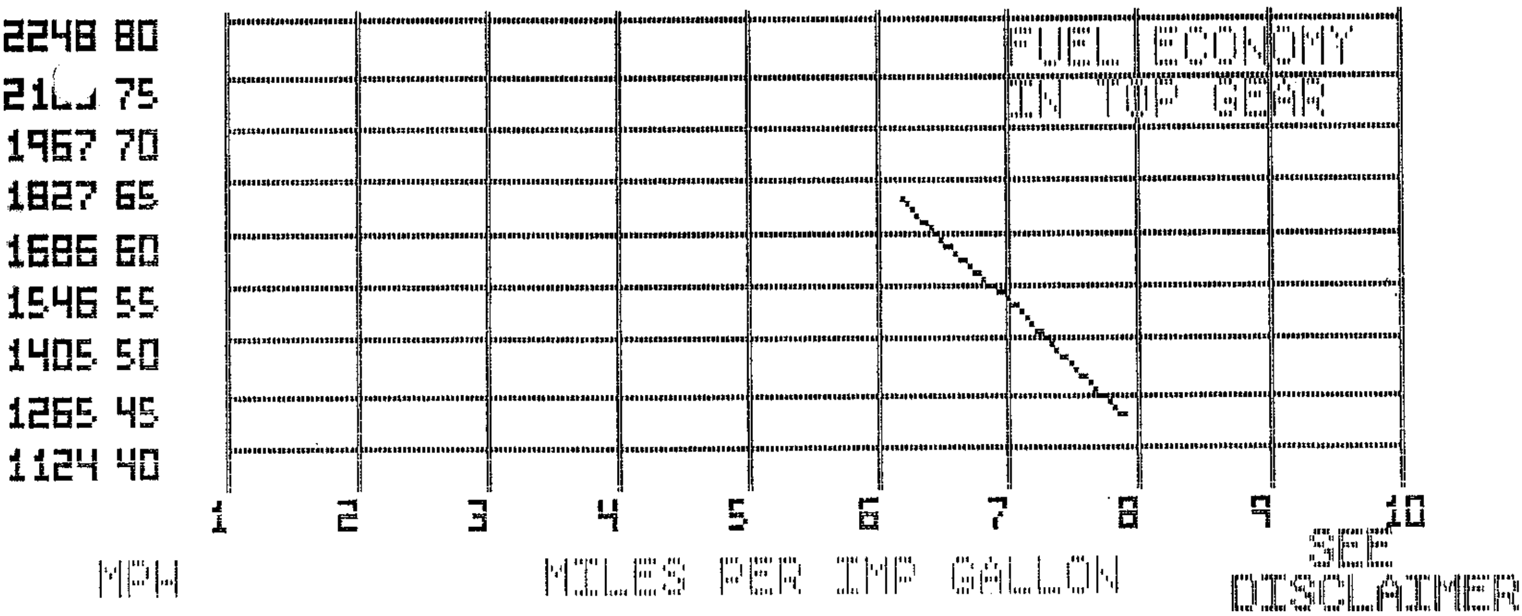
INSTANTANEOUS FUEL ECONOMY CHART

** Run ID: 9**

In Imp. Gallons

ENGINE:	3406B ATAAC M	RTD POWER:	425 HP	RTD SPD:	1800 RPM
PK.TORQ:	1450 FT-LB	P-T SPD:	1200 RPM	TRANS:	FULLER RTO-14613
AXLE:		DRIVE AXLES:	2	TOTAL AXLES:	7
RATIO(S):	3.90	TRUCK:	TR/Double Van	WIDTH:	8 FT.
HEIGHT:	13.5	GVW/GCW:	98560 LBS	DRAG COEF:	.65
TIRES:	11.00X22.5 R	REV/MI:	497	ROAD SURFACE:	Asphalt
RLG RES:	13.3 LBS/TON	ACC HP:	11	CRUISE SPEED:	60



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TRUCK PERFORMANCE ANALYSIS

** Run ID: 9** In Imp. Gallons

ENGINE:	3406B ATAAC M	RTD POWER:	425 HP	RTD SPD:	1800 RPM
PK.TORQ:	1450 FT-LB	P-T SPD:	1200 RPM	TRANS:	FULLER RTO-14613
AXLE:		DRIVE AXLES:	2	TOTAL AXLES:	7
RATIO(S):	3.90	TRUCK:	TR/Double Van	WIDTH:	8 FT.
HEIGHT:	13.5	GVW/GCW:	98560 LBS	DRAG COEF:	.65
TIRES:	11.00X22.5 R	REV/MI:	497	ROAD SURFACE:	Asphalt
RLG RES:	13.3 LBS/TON	ACC HP:	11	CRUISE SPEED:	60

THIS COMPUTER PROGRAM HAS BEEN DESIGNED TO BE USED AS A COMPARATIVE, DRIVELINE SPECIFICATION TOOL AND TO ESTIMATE PERFORMANCE AND/OR FUEL ECONOMY FOR THE VEHICLE AND PARAMETERS DESCRIBED IN THE INPUT SECTION OF THE REPORT. A REVIEW OF THE INPUT IS NECESSARY TO ASSURE THE OUTPUT RESULTS ARE COMPATIBLE. SINCE SOME OF THE DATA IS BASED ON AVERAGE VALUES, THIS REPORT MAY NOT REFLECT ACTUAL OPERATING CONDITIONS. DRIVER INFLUENCES, WEATHER, APPLICATION VARIATIONS AND OTHER DIFFICULT TO QUANTIFY VARIABLES WILL ALSO AFFECT REAL PERFORMANCE. THEREFORE, NEITHER CATERPILLAR, NOR THE CATERPILLAR DEALER CAN GUARANTEE THE PERFORMANCE INDICATED ON THIS COMPUTER SIMULATION.

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TRUCK PERFORMANCE ANALYSIS

** Run ID: 9** In Imp. Gallons

*** ENGINE: 3406B ATAAC M , CODE (TM7710),

RATED POWER BHP	RATED SPEED RPM	PEAK TORQUE FT-LB	PEAK TORQUE RPM	FAN LOSS HP	ACCESSORY LOSS HP	ENGINE INERTIA FT-LB-SEC2	ENGINE DISP CU IN	LOAD STARTING FT-LBS
425	2100	1450	1200	0	11	2.3	893	644.

*** TRANSMISSION: FULLER RTO-14613

*** REAR AXLE:
NO OF DRIVE AXLES: 2
TOTAL NO OF AXLES: 7
RATIO(S): 4.33

*** TRUCK TYPE: TR/Double Van
SIDE: Smooth WIDTH: 8 FT.
TOP: Closed HEIGHT: 13.5 FT.
DUTY CYCLE: Line Haul GVW/GCW: 98560 LBS

COEFFICIENT OF DRAG FOR BASIC CONFIGURATION: .77
MODIFIED COEFFICIENT OF DRAG: .65

*** TIRES: 11.00X22.5 R
TIRE TYPE: Radial
REV/MILE: 497

*** COURSE SURFACE: Asphalt
ROLLING RESISTANCE 13.3 LBS/TON
ENVIRONMENTAL CONDITIONS:
ZERO WIND VELOCITY, 77 DEG F., 500 FT ALTITUDE.

Engine Files Last Updated : Jan 1,1989

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PREPARED BY: WARREN SARGENT

TRUCK PERFORMANCE ANALYSIS

** Run ID: 9** In Imp. Gallons

ENGINE: 3406B ATAAC M	RTD POWER: 425 HP	RTD SPD: 2100 RPM
PK.TORQ: 1450 FT-LB	P-T SPD: 1200 RPM	TRANS:FULLER RTO-14613
AXLE:	DRIVE AXLES: 2	TOTAL AXLES: 7
RATIO(S): 4.33	TRUCK:TR/Double Van	WIDTH: 8 FT.
HEIGHT: 13.5	GVW/GCW: 98560 LBS	DRAG COEF: .65
TIRES: 11.00X22.5 R	REV/MI: 497	ROAD SURFACE: Asphalt
RLG RES: 13.3 LBS/TON	ACC HP: 11	CRUISE SPEED: 60

SUMMARY OF VEHICLE PERFORMANCE PARAMETERS

MAIN TRAN GEAR	AUX TRAN NO.	TRANS GEAR RATIO	TOTAL GEAR RATIO	MPH AT RATED RPM	RPM AFTER SHIFT
1	0	12.56	54.38	4.7	0
2	0	8.32	36.03	7.0	1391
3	0	6.18	26.76	9.5	1560
4	0	4.54	19.66	12.9	1543
5	0	3.38	14.64	17.3	1563
6	0	2.46	10.65	23.8	1528
7	0	2.15	9.31	27.2	1835
8	0	1.83	7.92	32.0	1787
9	0	1.60	6.93	36.6	1836
10	0	1.34	5.80	43.7	1759
11	0	1.17	5.07	50.0	1834
12	0	1.00	4.33	58.5	1795
13	0	0.87	3.77	67.3	1827

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CATERPILLAR INC.

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TRUCK PERFORMANCE ANALYSIS

** Run ID: 9** In Imp. Gallons

ENGINE: 3406B ATAAC M	RTD POWER: 425 HP	RTD SPD: 2100 RPM
PK.TORQ: 1450 FT-LB	P-T SPD: 1200 RPM	TRANS:FULLER RTO-14613
AXLE:	DRIVE AXLES: 2	TOTAL AXLES: 7
RATIO(S): 4.33	TRUCK:TR/Double Van	WIDTH: 8 FT.
HEIGHT: 13.5	GVW/GCW: 98560 LBS	DRAG COEF: .65
TIRES: 11.00X22.5 R	REV/MI: 497	ROAD SURFACE: Asphalt
RLG RES: 13.3 LBS/TON	ACC HP: 11	CRUISE SPEED: 60

SUMMARY OF VEHICLE PERFORMANCE PARAMETERS

MAIN TRAN GEAR NO.	AUX TRAN GEAR NO.	DRIVE TRAIN HP LOSS	AIR RESIST HP LOSS	ROLL. RES. HP LOSS	GROSS DEMAND HP	PERCENT OF RATED WHEEL HP AT SHIFT	% GRADE CAP. AT PEAK TORQ RPM	MAX STARTING GRADE
1	0	80.5	0.0	8.2	99.7	0.0	41.4	15.0
2	0	73.2	0.1	12.3	96.7	92.5	26.5	7.1
3	0	65.6	0.4	16.6	93.5	98.5	19.7	2.4
4	0	59.7	0.9	22.6	94.2	98.0	14.4	0.0
5	0	55.6	2.2	30.3	99.1	98.6	10.6	0.0
6	0	52.3	5.7	41.7	110.7	97.6	7.6	0.0
7	0	51.2	8.6	47.7	118.4	102.7	6.6	0.0
8	0	50.0	13.9	56.0	131.0	102.6	5.5	0.0
9	0	49.2	20.8	64.1	145.1	102.7	4.7	0.0
10	0	48.3	35.5	76.5	171.2	102.5	3.8	0.0
11	0	47.7	53.3	87.6	199.6	102.7	3.2	0.0
12	0	47.5	85.3	102.5	246.4	102.6	2.6	0.0
13	0	47.5	129.6	117.8	305.9	102.7	2.1	0.0

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TRUCK PERFORMANCE ANALYSIS

** Run ID: 9**

In Imp. Gallons

ENGINE:	3406B ATAAC M	RTD POWER:	425 HP	RTD SPD:	2100 RPM
PK.TORQ:	1450 FT-LB	P-T SPD:	1200 RPM	TRANS:	FULLER RTO-14613
AXLE:		DRIVE AXLES:	2	TOTAL AXLES:	7
RATIO(S):	4.33	TRUCK:	TR/Double Van	WIDTH:	8 FT.
HEIGHT:	13.5	GVW/GCW:	98560 LBS	DRAG COEF:	.65
TIRES:	11.00X22.5 R	REV/MI:	497	ROAD SURFACE:	Asphalt
RLG RES:	13.3 LBS/TON	ACC HP:	11	CRUISE SPEED:	60

TOP SPEED IN HIGHEST GEAR ON ZERO PERCENT GRADE

GCW LB	REAR AXLE RATIO	TRANS GEAR RATIO	TOTAL GEAR RATIO	MPH TOP SPEED	ENGINE SPEED RPM
98560	4.33	0.87	3.77	69.5	2168

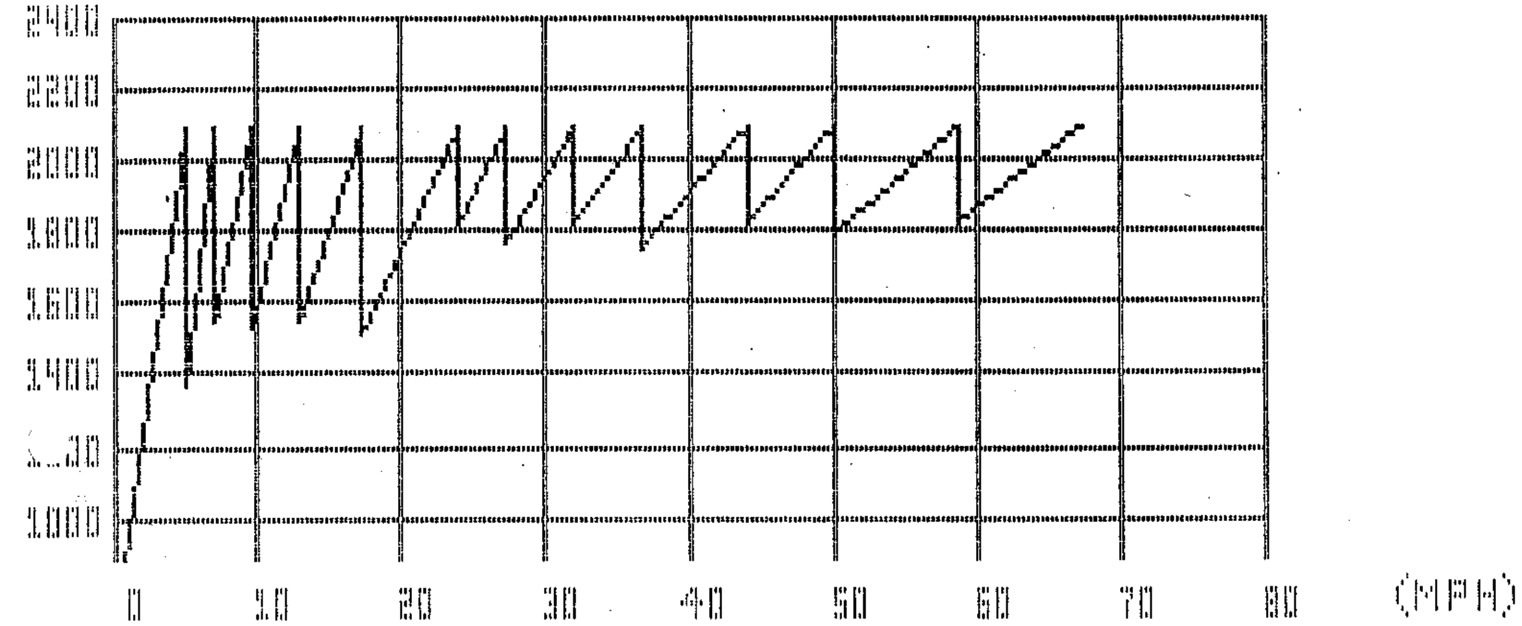
ENGINE ACCESS HP LOSS	DRIVE TRAIN HP LOSS	AIR RESIST HP LOSS	ROLLING RESIST HP LOSS	GROSS DEMAND HP
11.4	41.9	142.7	121.7	317.6

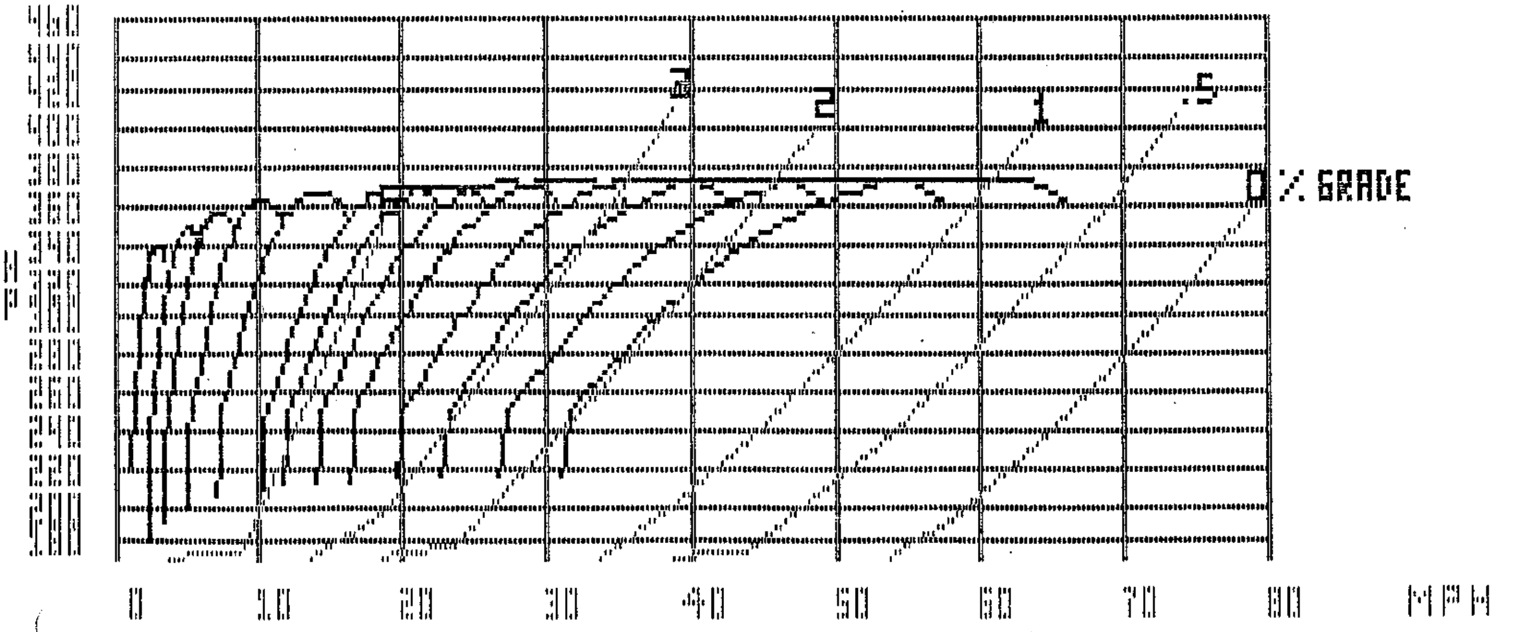
Engine Files Last Updated : Jan 1,1989

CATERPILLAR INC.

PREPARED BY: WARREN SARGENT

Eng: 3406B ATAAC M 425 hp @2100 RPM
Trans: RTO-14613 Axle: 4.33:1
Tires: 11.00X22.5 GVW/GCW:98560





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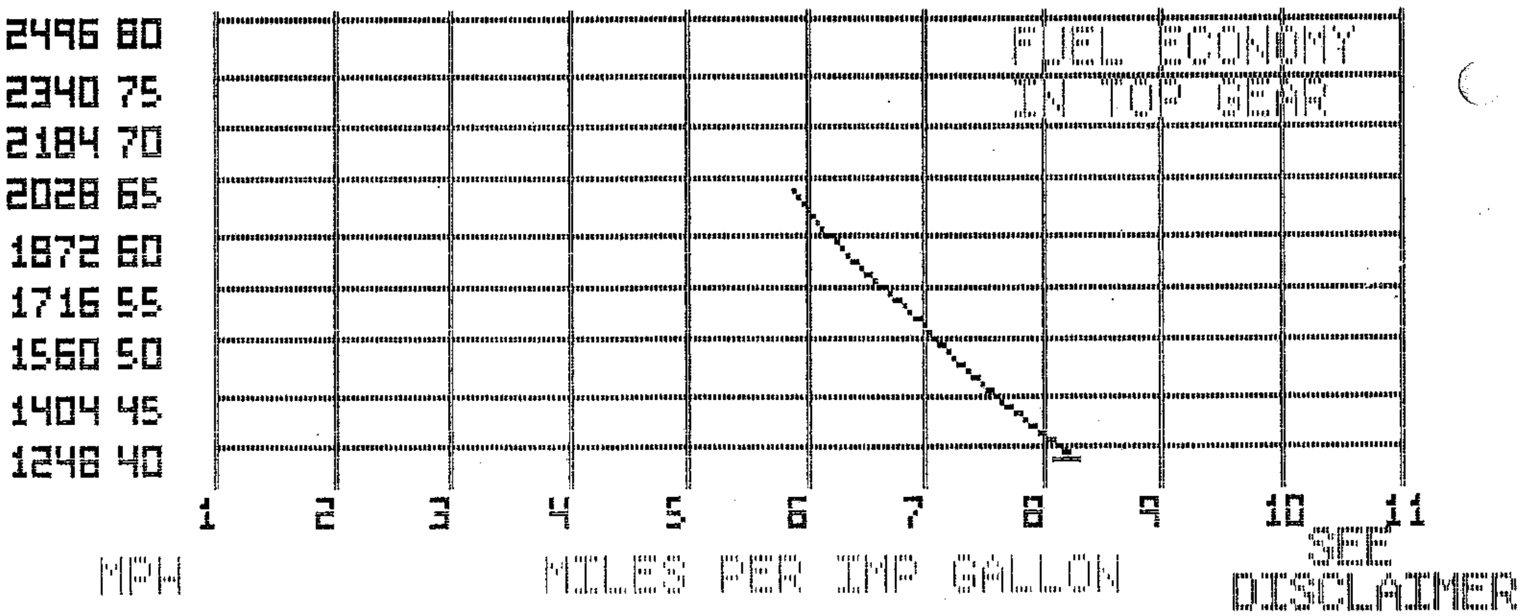
INSTANTANEOUS FUEL ECONOMY CHART

** Run ID: 10**

In Imp. Gallons

ENGINE:	3406B ATAAC M	RTD POWER:	425 HP	RTD SPD:	2100 RPM
PK.TORQ:	1450 FT-LB	P-T SPD:	1200 RPM	TRANS:	FULLER RTO-14613
AXLE:		DRIVE AXLES:	2	TOTAL AXLES:	7
RATIO(S):	4.33	TRUCK:	TR/Double Van	WIDTH:	8 FT.
HEIGHT:	13.5	GVW/GCW:	98560 LBS	DRAG COEF:	.65
TIRES:	11.00X22.5 R	REV/MI:	497	ROAD SURFACE:	Asphalt
RLG RES:	13.3 LBS/TON	ACC HP:	11	CRUISE SPEED:	60



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TRUCK PERFORMANCE ANALYSIS

** Run ID: 9**   In Imp. Gallons

ENGINE:	3406B ATAAC M	RTD POWER:	425 HP	RTD SPD:	2100 RPM
PK.TORQ:	1450 FT-LB	P-T SPD:	1200 RPM	TRANS:	FULLER RTO-14613
AXLE:		DRIVE AXLES:	2	TOTAL AXLES:	7
RATIO(S):	4.33	TRUCK:	TR/Double Van	WIDTH:	8 FT.
HEIGHT:	13.5	GVW/GCW:	98560 LBS	DRAG COEF:	.65
TIRES:	11.00X22.5 R	REV/MI:	497	ROAD SURFACE:	Asphalt
RLG RES:	13.3 LBS/TON	ACC HP:	11	CRUISE SPEED:	60

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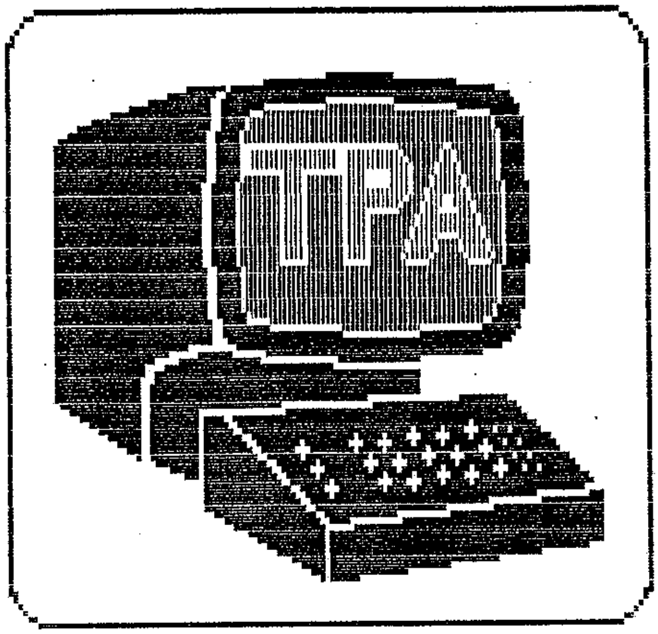
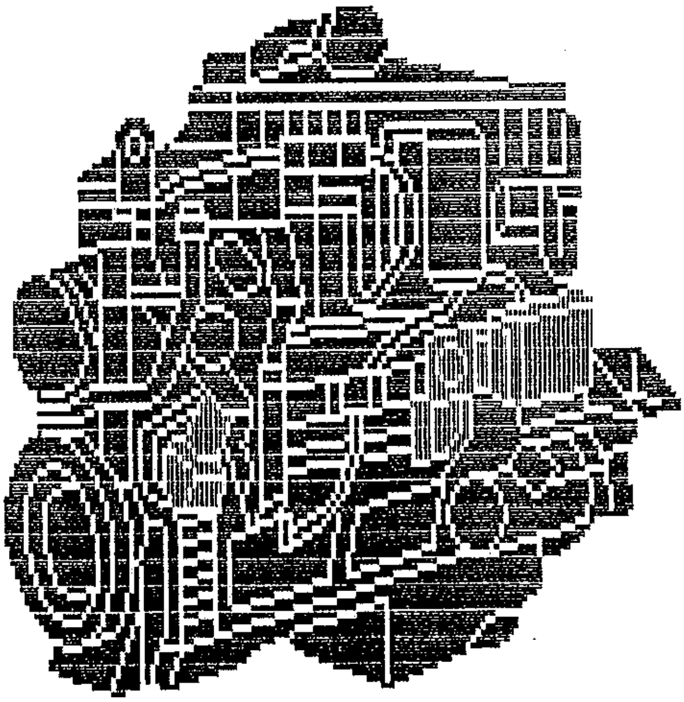


* TRUCK PERFORMANCE ANALYSIS

+ To get the right truck for the job, drivetrain components must be analyzed together to ensure that the truck's performance meets the requirements of the application.

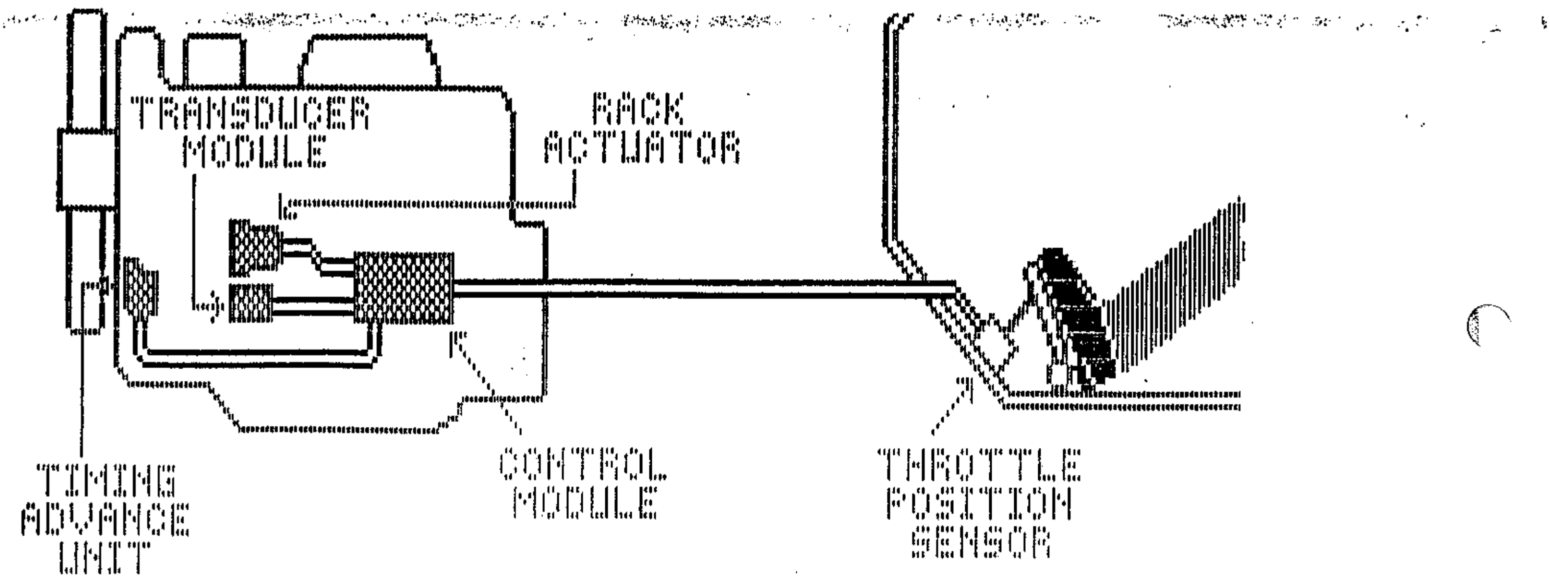
* PROGRAMMABLE ELECTRONIC ENGINE CONTROL

+ Integrally designed with the engine to control fuel flow and injection timing.
+ Engine and vehicle parameters can be set for maximum efficiency.



* COMPONENTS

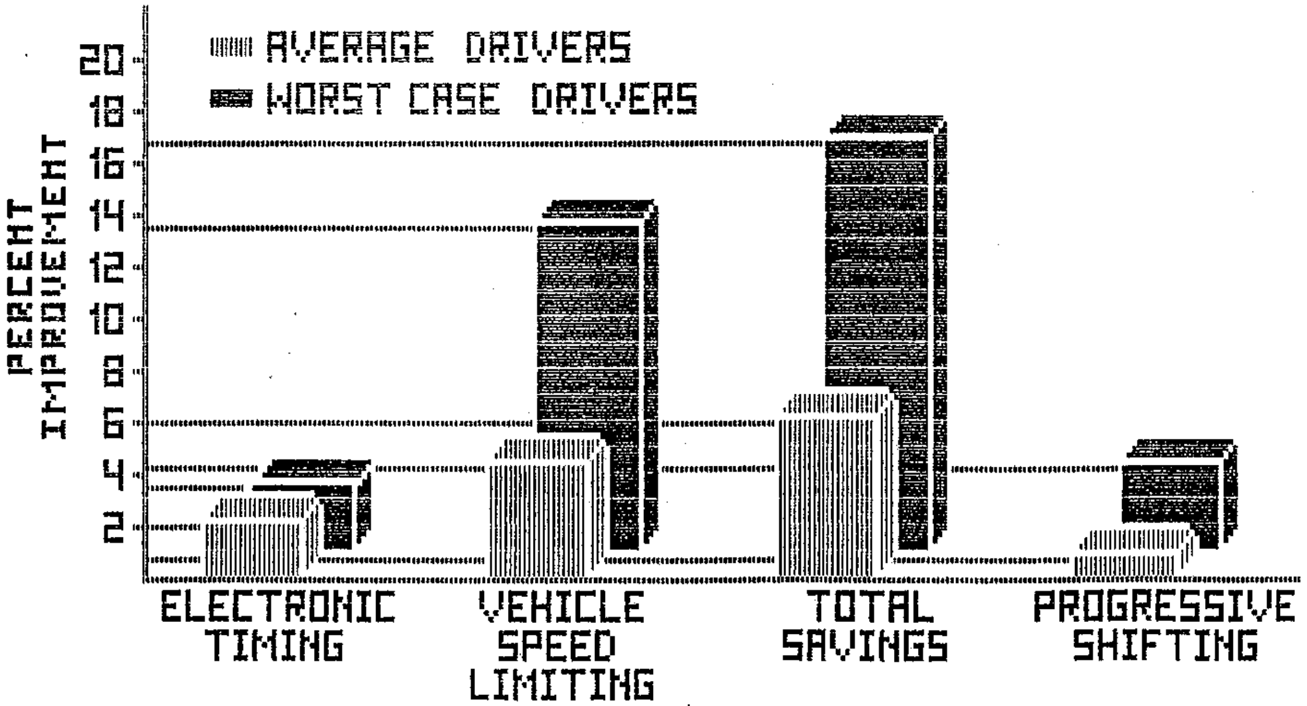
+ PEEC is an integral microprocessor-based Electronic engine control.
+ The system is made of four basic parts that are engine mounted to simplify installation.



* PEEC SYSTEM OVERVIEW

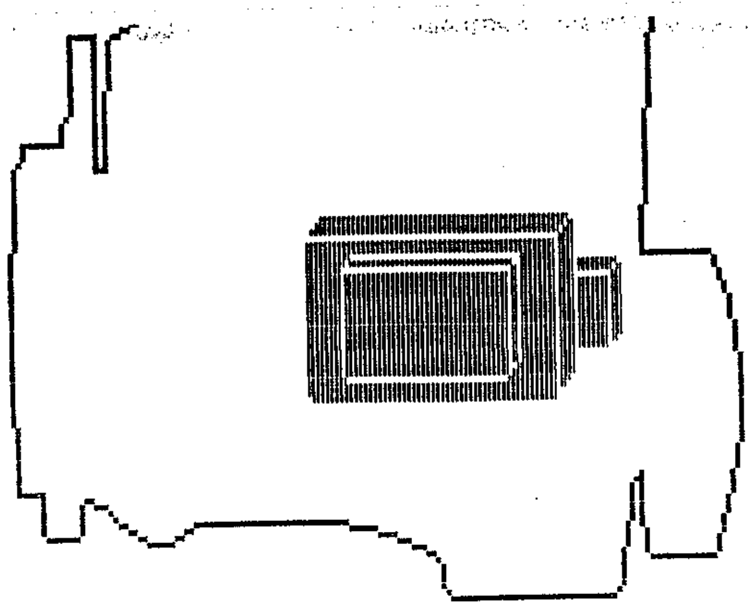
+ **Cat's Programmable Electronic Engine Control (PEEC) offers many engine and vehicle functions including: Electronic governing, Fuel air ratio and injection timing control, Cruise control, Vehicle and engine speed limiting, and Progressive shifting.**

3406B PEEC FUEL ECONOMY IMPROVEMENTS

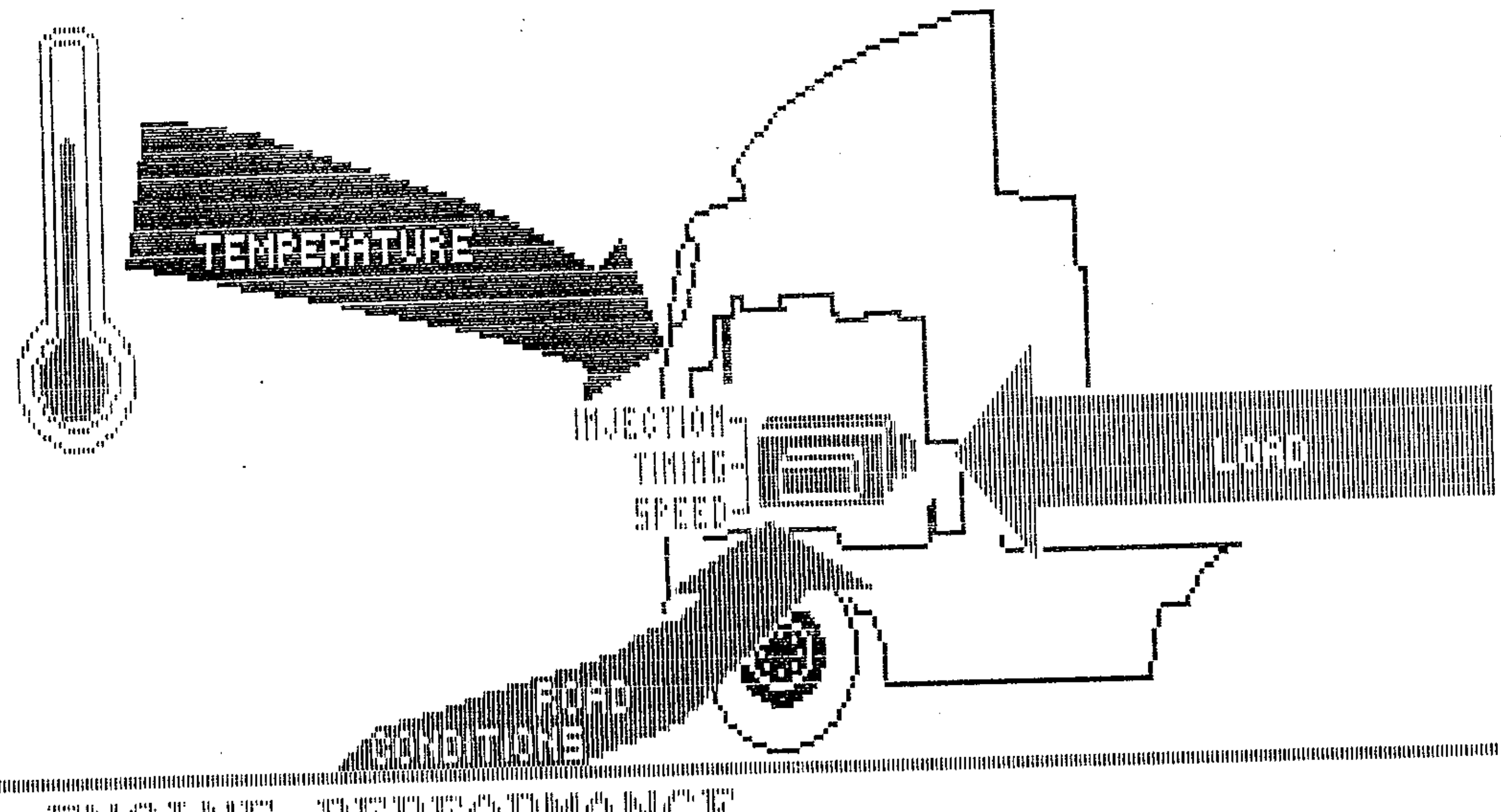


* FUEL CONSUMPTION IMPROVEMENT

+ **By using the PEEC system, your total savings on fuel economy could be up to 17%, depending on driver and vehicle application.**



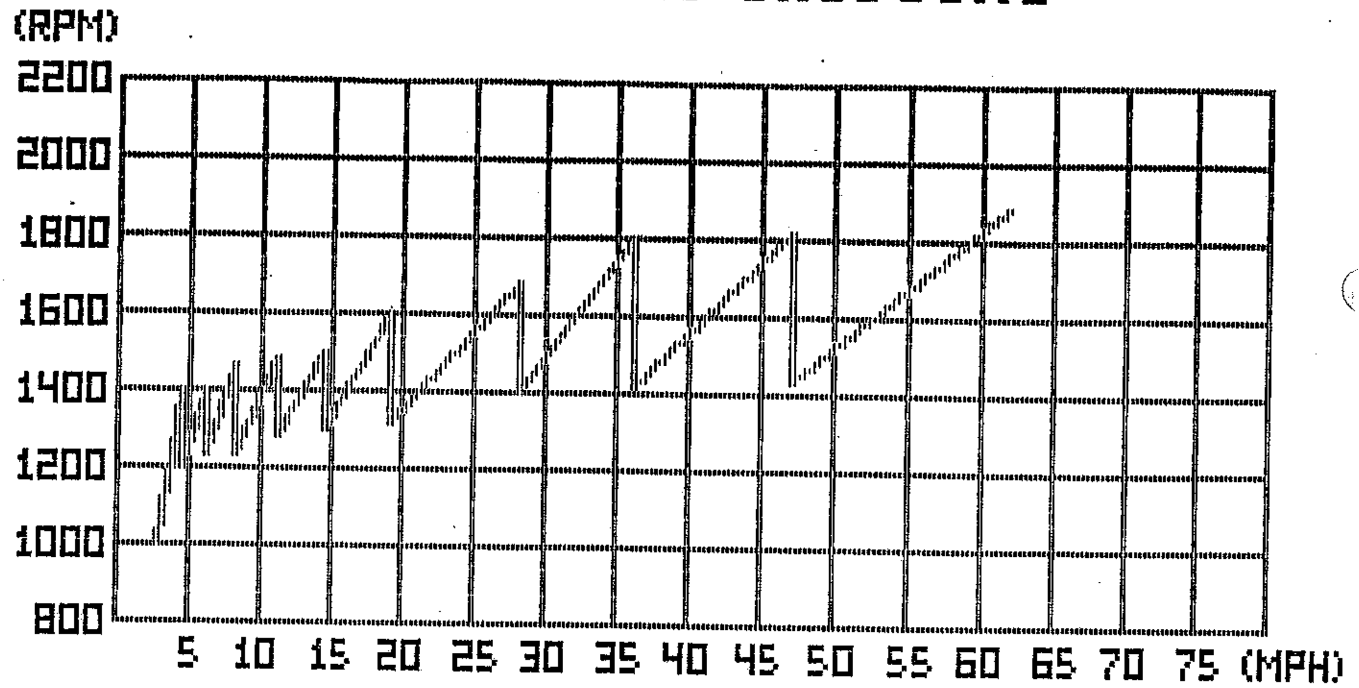
* ELECTRONIC CONTROL SYSTEM
  + Integrally designed into the engine's fuel and air inlet/exhaust systems
  + Provies faster, more accurate control of timing and fuel/air ratio, with few mechanical components



* ENGINE PERFORMANCE

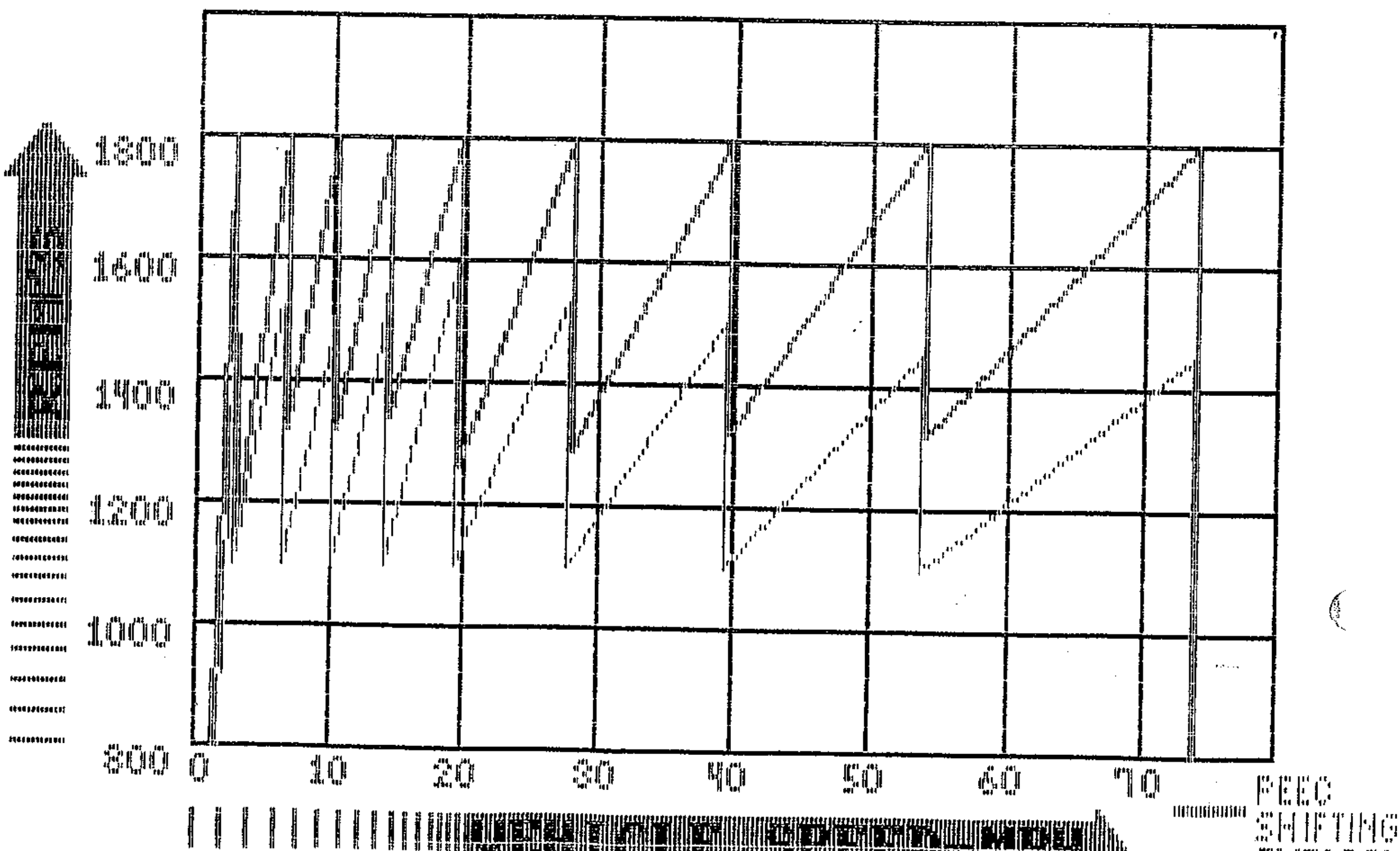
  + Engine speed, timing and injection are varied by the ECM to optimize the engine's performance according to the operating conditions

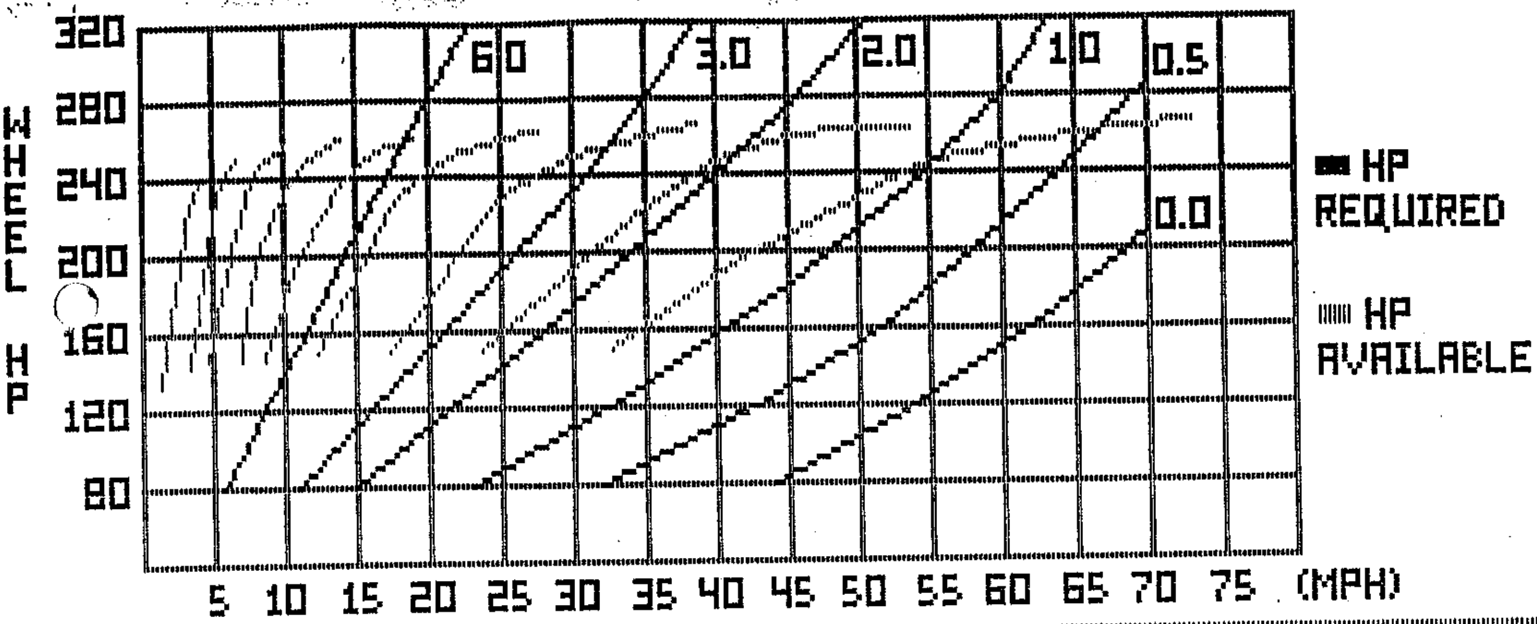
PROGRESSIVE SHIFTING



+ Progressive shifting is achieved by shifting as low in the RPM range as possible, using only the engine power required to move the load.
This avoids excess fuel consumption and lowers operating costs.

GEAR FAST, RUN SLOW

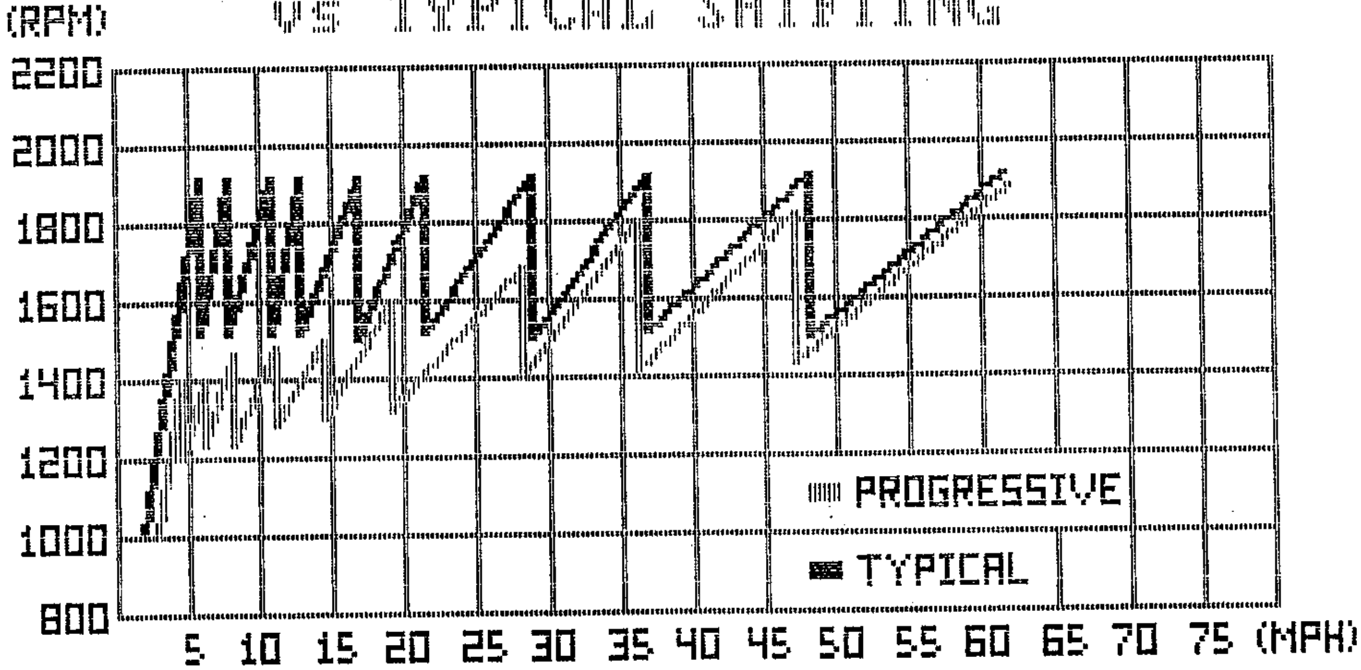




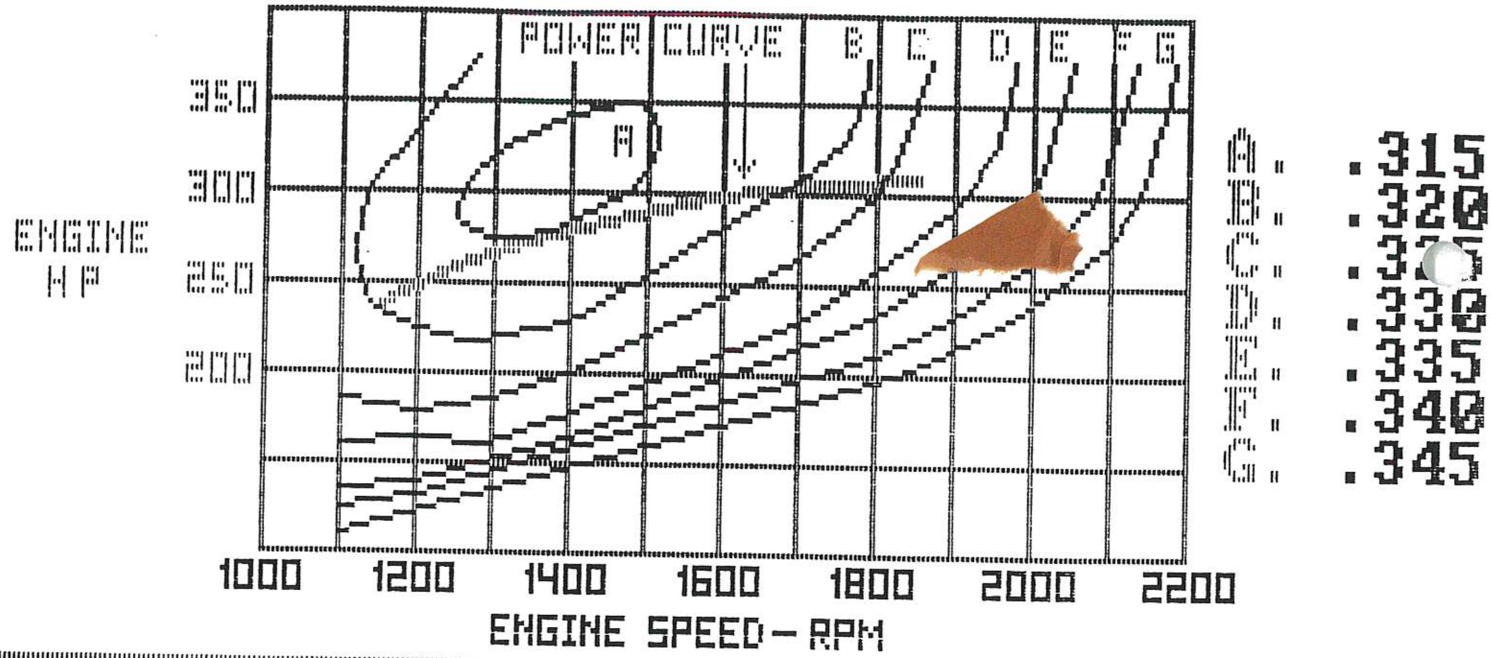
* HP REQUIRED VS. HP AVAILABLE

+ By staying in the highest possible gear and holding down speed, more HP will be available and fuel efficiency will improve.

PROGRESSIVE SHIFTING VS TYPICAL SHIFTING

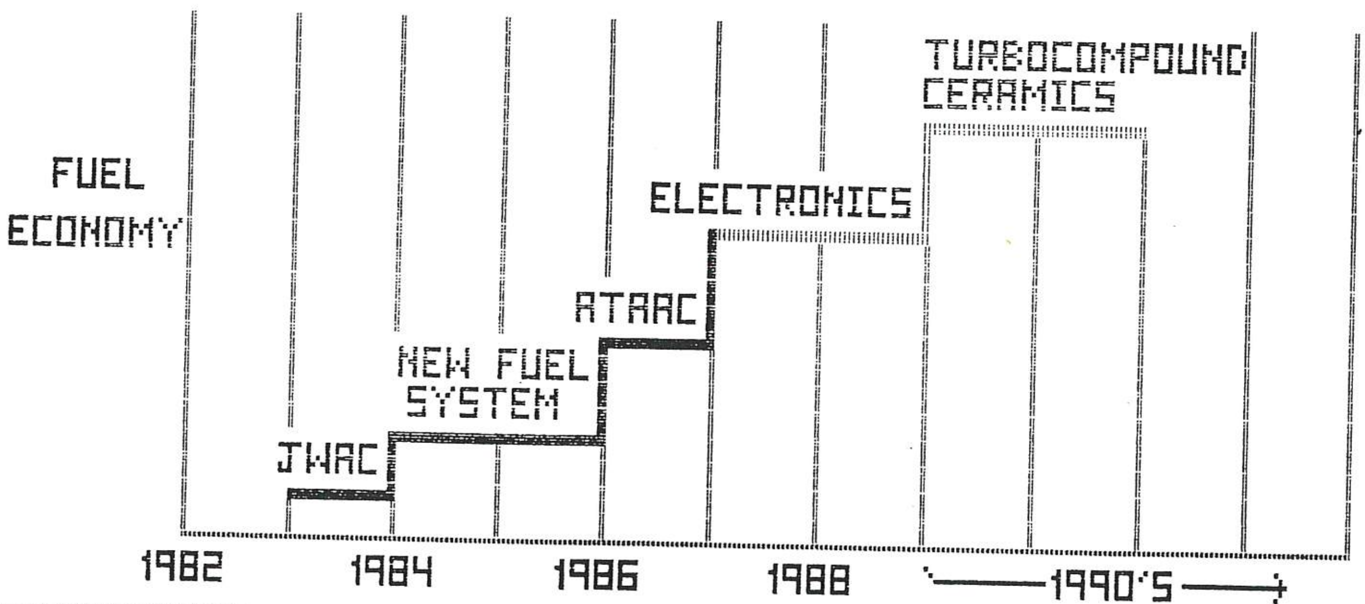


PROGRESSIVE	TYPICAL
+ Uses only the engine HP needed.	- Uses excess engine HP.
+ Fuel efficient.	- Harder on the driveline.



* TYPICAL FUEL MAP

+ By plotting the fuel map and the power curve of an engine, it is possible to visually estimate the performance of the truck engine.



* 3406B FUEL ECONOMY IMPROVEMENT

+ This graph summarizes the past and future efforts of Caterpillar to improve the fuel economy of the 3406B.

SELF STEERING AXLES AND THE COMMERCIAL VEHICLE

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Presented at

The Third International IRTENZ Seminar
Christchurch, New Zealand

August 1-3, 1989

From a quiet beginning some thirty-five years ago in the northern Italian city of Verona, home to Romeo and Juliette, the self steering axle is now widely used throughout the world in commercial vehicle applications. Clearly, the self steering axle will never match the notoriety of the world's most famous lovers; however, parallels can be drawn with regard to the levels of passion and uncertainty that surround its use.

The reason for this reaction can be attributed to the lack of technical information describing the influence that self steering axles have on vehicle performance. It is also not widely known what characteristics the axle should have. In addition, the self steering axle has evolved from the principle of 'design precedent', that is, it has been developed in the field without the benefit of analytical study focusing on the detailed mechanics and dynamics of the axle and its effect on vehicle behaviour.

This paper will attempt to pull together elements of theory and practice pertaining to the self steering axle and its use. Much of this information presented is the result of a major research study (1) on the Canadian C-train conducted at the Vehicle Dynamics Laboratory of the National Research Council of Canada with partial support from the Roads and Transportation Association of Canada.

Originally, the self steering axle was designed to be used as the second axle of a tandem axle suspension of a straight truck (lorry) to improve off tracking and reduce tire scuffing in tight turns which affected both the vehicle and the cobblestone roadways. Used in a tandem axle system, the load equalization of the two axles was biased in favour of the fixed lead axle which carried at least sixty percent of the tandem axle group load. Since the suspension design ensured that the lead axle always carried the majority of the load of the axle group, it was assured that this fixed axle could provide the cornering force requirement of the vehicle. The self steering axle was not designed to produce primary cornering forces for the vehicle during high speed turns.

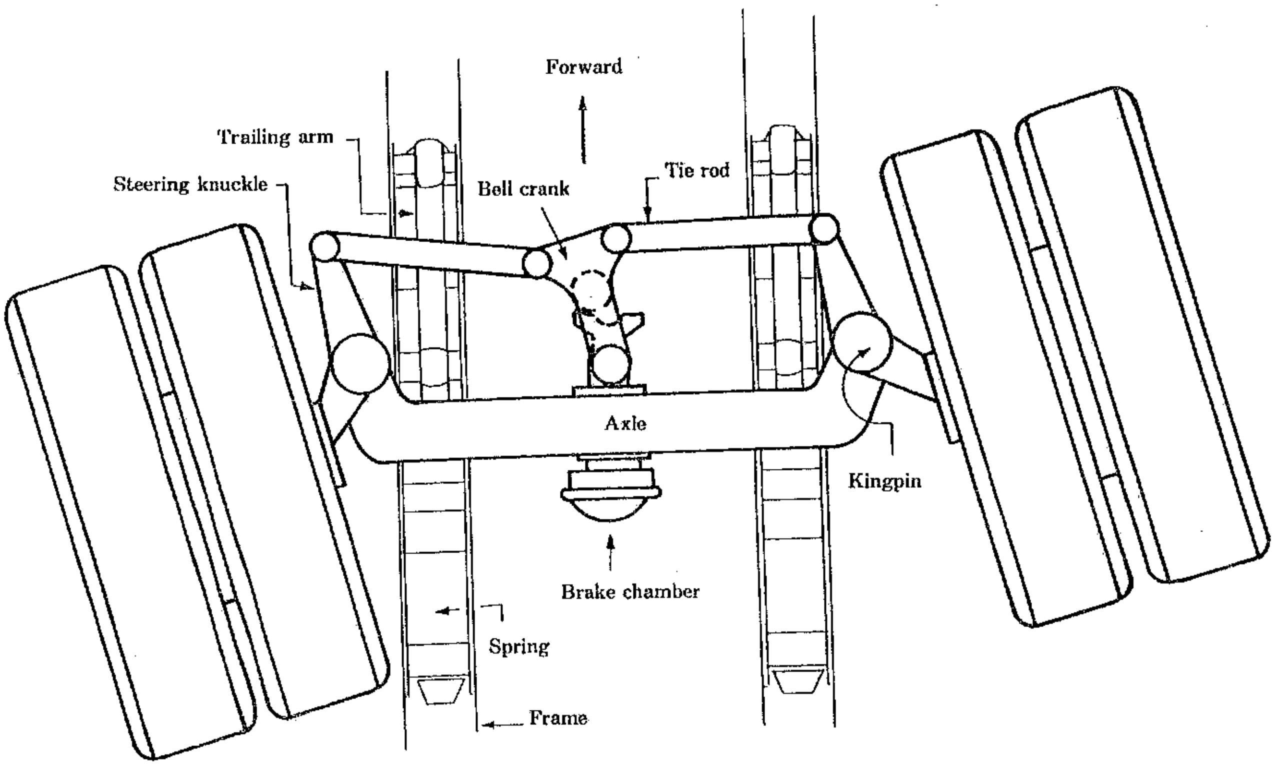

Fig. 1 Main Components of the BPW Self Steering Axle Tested in 1983 (1)

The self centring or zero steer angle biased forcing system found on most self-steering axles is used to offset the effects of unbalanced braking between wheels of the axle and as an assistance mechanism that returns the steering axle to the zero steer position quickly and smoothly. Without this centring assistance device, the internal friction within the self-steering axle could freeze the axle in a steered position until the slip angles of the tires on the self-steering axle were large enough to overcome these friction forces. Because of the "stiction" phenomenon associated with sliding or Coulomb friction, and considering that the side force characteristic of a tire is analogous to a spring, once sufficient side force has been generated to overcome the friction in the system, there is a rapid change in steer angle of the self-steer axle resulting in a lateral force impulse, or jerk which is transmitted to the vehicle.

Much of the material contained in this paper was the result of the Canadian study which examined the use of self steering axles in the C-train, Figs. 1,2. The C-train places unique demands on the self-steering axle. The C-dolly effectively de-couples the two trailers vertically, i.e. there is little or no vertical load transfer between the leading and following trail-

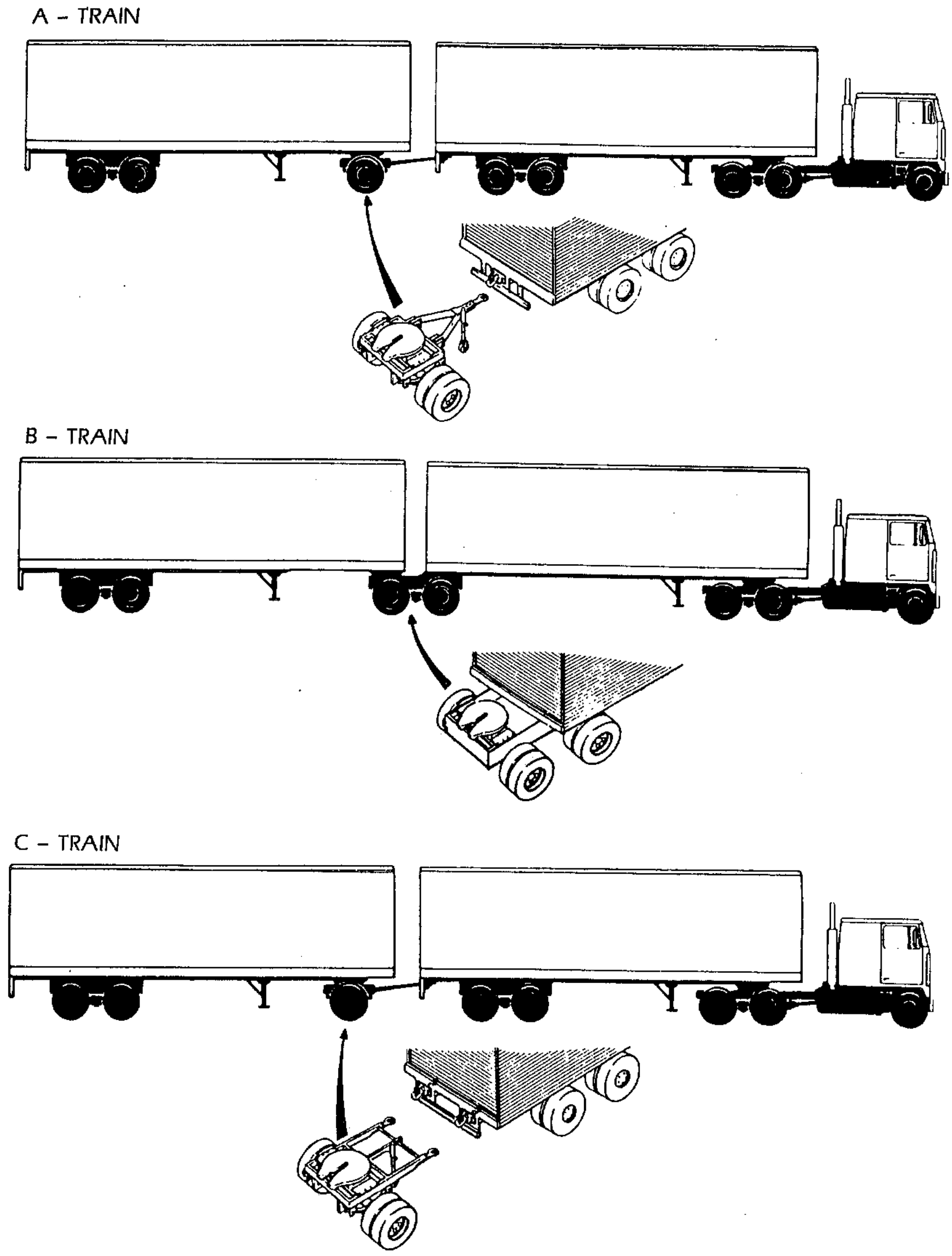

Fig. 2 Common Canadian Configurations

ers. But the C-dolly is rigidly coupled laterally so that lateral cornering forces can be transferred from the following trailer to the leading trailer. If the self steering axle is castering freely, thereby providing no cornering forces, approximately half of the lateral force required by the following trailer during cornering is transferred through the dolly to the tires of the lead trailer.

Under certain conditions this extra force demand on the tires of the lead unit can result in excessive high speed out-board offtracking and possible yaw divergence of the trailers. One such condition that could lead to this occurrence is when the lead trailer is lightly loaded and the following trailer is full. Since there is no vertical load transfer between the trailers, the tires of the lead trailer would be lightly loaded, therefore incapable of generating much cornering force, yet the fully loaded following trailer would have high cornering force requirements which would have to come from the lead trailer tires. This weakness associated with free castering self steering axles can be overcome by using a centring force system.

Self steering axles are also vulnerable to unequal longitudinal forces acting through the wheels of the axle. This could occur because of frozen or poorly adjusted brakes, failure of brakes on one side of the axle or variations in the road surface friction between each side of the axle during heavy brake applications. A very high level of longitudinal force unbalance between tires of a self-steering axle can be experienced when one side of the axle is on a paved part of the road and the other is on loose material such as a soft shoulder or on slushy, high density snow. If sufficiently high, the force unbalance can result in an axle steer angle relative to the vehicle velocity vector which will produce lateral forces that can, in some cases, change the direction of travel of the trailers.

The weaknesses associated with the free castering self steering axles can be offset with the use of an appropriate centring force system. The force requirements are higher than those associated with self steering axles in the traditional straight truck application. Most of the analysis conducted during this research project focused on this issue. Because of the complexity and length of the analysis, it could not be included in this paper. It can be found in the main report (1).

Manufacturers of self steering axles offer a wide range of axle load capacities and axle track dimensions. Axle capacities range between 6 and 15 tonnes. Track width is dependent on the requirements of the customer; however, both 2.4 and 2.6 meter outer dimension track widths are common. For the automotive steer type axle the caster dimension is approximately 150 mm and the lateral moment arm from the kingpin to the centre of the dual tire contact area, referred to as kingpin offset dimension, varies between 370 mm to 430 mm depending on manufacturer or the requirements of the purchaser. All automotive self steering axles examined use kingpins with virtually no inclination. Some manufacturers set about 1° of camber in the axle to allow for slight bending of the axle under rated load. This ensures that both tires of a dual pair will be normal to the road surface when fully loaded.

The alignment of the axle and the toe in adjustment is achieved with a threaded sleeve coupler or with an eccentric bushing and lock nut assembly. All manufacturers recommend toe in settings varying from 0.05 to 0.15 degrees measured with respect to the rotational plane of the wheel and the centre line axis of the vehicle.

Maximum steer angles of the axles vary between models and manufacturers. They range from about 14 to 24° off centre. Along with the centring force system, automotive type self steering axles are often fitted with shock absorbers to dampen out steer impulses and to retard the dynamic steer response of the system.

Spring centres on automotive style axles are generally quite narrow because of interference allowances required by the tires of the steer axle as they steer. For a steering axle fitted with dual tires on a 2.6 meter track, typical spring centre dimensions range from 0.69 to 0.75 meters. If super singles are used, the spring centres can be increased to about 1.0 meters.

The turn table type steer axle has much larger spring centres because the tires do not steer relative to the suspension. The tires, suspension and sub-frame all rotate with respect to the main frame, therefore spring centres can be as wide as 1.1 meters.

Locking Mechanism

Self steering axles require locking mechanisms to immobilize the steering action of the axle on centre when the vehicle moves in reverse. Without it the axle will instantly steer to its limit of travel and the high forces generated by the tires can result in mechanical failure of the steering system. The lock is a pin type device which engages into a hole in a steel plate attached to the tie rod assembly. The turn table type dolly has a similar device which pins the main dolly frame and the sub-frame together. The locking devices can be controlled from the tractor cab if fitted with the appropriate hardware.

For a short time a particular turn table dolly was produced with a unique locking feature that injected a pin into one of a series of locking holes when the dolly brakes were applied. The locking holes were arranged in a circular fashion allowing for locking of the steer axle system at steer angles other than zero. Because of the design of the pin it would occasionally jam in the locking hole while the axle was in a steered position despite the vehicle having re-aligned itself. The problems associated with such a failure are obvious and the practice was curtailed. It is worth noting that this idea may not be without merit. Since the steer axle is sensitive to unbalanced longitudinal wheel forces of the type experienced during heavy brake applications of split friction surfaces, it may be beneficial to have a locking device immobilize the axle when high brake forces the steering of the axle. In addition to this, the net caster dimension diminishes with steer angle.

Conclusions

Research has shown that self steering axles can be used successfully provided that they are of proper design and are engineered within the vehicle. Key elements to consider are:

- A self steering axle must have a centring force mechanism which may have different characteristics depending on application.

- The self steering axle must have proper load sharing with adjacent axles.

- The self steering axle must meet side force and differential longitudinal wheel force specifications that may vary depending on the use of the axle.

- The self steering axle must not be used as the second axle of a twin steer front end.

- The self steering axle should not be used in high risk applications such as those found in off road situations.

- The self steering axle must have a locking device which can be activated by the driver in the cab of the vehicle. The axle should be locked when rough road conditions are experienced or when the vehicle is driven in reverse.

- Self steering axles should be equipped with uniform tires.

- Self steering axles should be inspected annually to ensure that the self centring mechanism and all moving parts are in proper working order.

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