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CONSULTING ENGINEERS

Report No. EPA-460/3-81-011

PREDICTIONS OF THE PERFORMANCE AND EXHAUST EMISSIONS PRODUCED BY SMALL LIGHT DUTY VEHICLES POWERED BY DI AND IDI DIESEL ENGINES

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S U M M A R Y

This report describes an exercise in which a computer simulation program was used to predict the likely performance, fuel economy and exhaust emission levels of light duty vehicles weighing from 1000 to 2000 lb when powered by naturally aspirated diesel engines of 0.8 litre displacement having direct injection (DI) and indirect injection (IDI) combustion systems. It was assumed that the vehicles were fitted with an efficient continuously variable transmission.

Based on currently available engine data it appears that the 0.8 l DI engine would not comply with current U.S. exhaust emissions legislation (.41/3.4/1.0 g/mile HC/CO/NOx) when fitted to vehicles weighing more than 1500 lb, but other vehicle performance characteristics (apart from noise and vibration) may be acceptable.

The predicted results suggest that the 0.8 l IDI engine might prove to be an acceptable power unit in terms of vehicle performance and exhaust emissions in vehicles weighing up to 1750 lb.

Predicted fuel economy over the FTP (urban cycle) for a 1000 lb vehicle using the DI and IDI engines was 94 and 86 miles/US gall. (Highway results 86 and 79 miles/US gall.) respectively, in the 2000 lb vehicle the corresponding figures were 56 and 52 miles/US gall. (and 56 and 50 miles/ US gall, Highway).

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1. INTRODUCTION

Increasing emphasis is being placed on the need for improved vehicle fuel economy. Two approaches currently being used in order to achieve this end are the development of lighter vehicles and the use of diesel engines in place of gasoline fuelled units. At present all production light duty diesel engines employ combustion systems of indirect injection (IDI) configuration; the relative advantage, from the point of view of better fuel economy, of direct injection (DI) combustion systems is generally appreciated (1, 2, 3)* and research and development aimed at producing DI engines which are acceptable in all respects for use in light duty vehicles is being conducted.

The objective of the work reported here was to predict, by computer simulation, the performance and exhaust emission characteristics of possible future light-weight passenger cars powered by naturally aspirated DI and IDI engines.

This work was requested by E.P.A. as a specific task to be carried out under the 1980/1981 year consulting agreement and the choice of engine type and size, and vehicle weights was agreed with E.P.A. at a meeting at Ann Arbor on 12th November 1980, see Ricardo note DP.80/1904.

2. SIMULATION PROCEDURE

2.1 Simulation Program

The computer program used (CVSIM) is primarily designed to predict the levels of exhaust emissions and fuel consumption to be expected from a vehicle during operation over a prescribed velocity cycle (in this case the LA4 and Highway drive cycles). Vehicle performance, in terms of acceleration times, can also be predicted.

Essentially, the program analyses the driving cycle and, from a knowledge of vehicle characteristics, calculates the engine speed and brake mean effective pressure (bmep) required to drive the vehicle over each velocity increment in turn. Knowing these two parameters the levels of exhaust emissions and fuel consumption are extracted from engine test bed performance maps which are represented in the program input data by two dimensional numerical arrays.

2.2 Simulated Engine/Vehicle Combinations

Two naturally aspirated diesel engines were employed in the simulation exercise. Both were of 0.8 litre total swept volume, in two cylinders; one had an IDI (Ricardo Comet) combustion system, the other was of DI configuration. The maximum power outputs of the IDI and DI engines were respectively: 25 bhp @ 4600 rev/min and 23 bhp @ 4400 rev/min. During simulation runs each engine was fitted in turn to vehicles of 1000, 1250, 1500, 1750 and 2000 lbs weight.

*Numbers in parentheses refer to references listed in Section 6.

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2.3 Input Data

The LA4 drive cycle was used by the program so that exhaust emission and fuel economy data corresponding to vehicle tests to the U.S. Federal Test Procedure would be generated. The Highway fuel economy test drive cycle was also used to produce appropriate estimates of fuel economy.

Estimates of performance data for each engine, i.e. torque curves and steady state emissions and fuel consumption maps, were based largely on actual measurements made on light duty IDI and DI engines; in general these engines had not been optimised with regard to particular parameters, e.g. it was assumed that EGR, which might be used to reduce NOx emissions or exhaust after treatment for reduction of HC or particulate emissions were not applied. Where necessary some allowance was made for the effects of differences in the numbers of cylinders and cylinder swept volume, since most available data related to larger engines with a greater number of cylinders.

With regard to vehicle characteristics the inertia and road load settings specified in the Federal Register (Vol. 42, No. 124, 28th June 1977) for each vehicle weight were used since only chassis dynamometer tests were being simulated.

The driving tyres (BR50-13) were assumed to have a rolling radius of 0.28 m (11 in). In order to derive final drive (axle) ratios it was assumed that maximum vehicle speeds occur at maximum power engine speed when using a primary drive (gearbox) ratio of 1:1. This produced the final drive ratios shown in Table 1 (calculated maximum speeds and acceleration times, based on the vehicle road load characteristics given in the Federal Register, for the various vehicle/engine combinations are also shown).

An automatic, continuously variable, transmission (CVT) was used in all the simulation exercises, this was assumed to have an overall span of 5:1. An overdrive top ratio of 0.8:1 was specified, the bottom ratio then became 4.0:1. It was assumed that ratio changes from one extreme to the other could be accomplished in 1 second. A gearbox transmission efficiency as shown in Fig. 1 was assumed. The final drive transmission efficiency was set at a constant value of 92%.

The polar moment of inertia of the various drive train components were assumed to be:-

driving wheels and axle - 1.6 $kg.m^2$

engine and CVT - 0.15 $kg.m^2$

3. RESULTS

The results produced by the simulation program for each vehicle/engine combination are listed in Table 2. Figs. 2 and 3 are graphs indicating the variation of exhaust emissions and vehicle performance with vehicle weight.

Due to the uncertainties noted below the level of confidence in the predicted results is rather low. With regard to the accuracy of the results predicted by the simulation program the following confidence levels may be considered realistic:-

Vehicle Performance (0-50 mile/h acceleration time)		±10%
Fuel Economy		±10%
Exhaust Emissions	HC	+75, -40%
	CO	±10%
	NOx	±10%
	Particulates	±15%

These levels do not include the element of uncertainty relating to the performance and emissions data used as input for the simulation. Especially in the case of the DI engine future research and development may result in significant improvements in all aspects of engine operation.

4. DISCUSSION

When considering the validity of the results produced by this exercise the following points should be noted:-

i] The computer program produces simulated results of transient tests using engine performance and emissions data derived under steady state conditions, it is likely that under true transient operation engine performance and emissions levels will show some variations from predicted results.

ii] All engine data used as input is nominally acquired at normal operating temperatures. In actual FTP vehicle tests the engine starts from cold and hence its performance and emissions during the early part of the test may be considerably different to what is predicted.

(These two points have been confirmed in previous work in which simulation results were compared with measured data when some divergence, especially in the case of HC emissions, has been observed).

iii] The input data relating to engine performance and emission levels were based on results achieved by engines operating over a fairly wide speed range (typically 1000-4500 rev/min) as required by current production engines having conventional transmission systems. When using a CVT it may prove advantageous in terms of fuel economy and emissions to optimise engine operation over a narrower speed range, most variation in vehicle speed then being achieved by employing a greater span of transmission ratios.

iv] All the input data relating to engine performance and emission levels were estimated based on a knowledge of the figures achieved by actual engines which generally had greater numbers of cylinders (in most cases four), and in some cases had larger cylinder displacements (up to 0.6 l).

v] Development of small DI engines suitable for use in light duty vehicle applications is at an early stage. Future work especially with regard to improved combustion systems and fuel injection equipment will probably lead to considerable reductions in exhaust emissions from the levels assumed in this exercise.

vi] The basic performance and emissions data used as input were typical average levels representative of current engines not optimised for any specific parameter. Lower emission levels may be achievable by employing exhaust after treatment, EGR, etc., but may incur penalties in terms of reduced engine performance and/or higher fuel consumption. With regard to small DI engines few data concerning the performance of current units are available and hence there is considerable doubt as to the fuel economy and emissions levels which may ultimately be achieved.

vii] Production versions of continuously variable transmissions having the characteristics assumed for this exercise are not yet available.

viii] The vehicle road load characteristics are assumed to be as set out in the Federal Register. In real vehicles aerodynamic drag and rolling resistance may be significantly different so that performance levels may show considerable variations.

As would be expected the results of this exercise suggested that increased vehicle weight caused increases in exhaust emission levels and fuel consumption while vehicle performance, in terms of acceleration time deteriorated.

An interesting result of this exercise is that predicted fuel economy over the LA4 (Urban) drive cycle is superior to that achieved during the Highway cycle. Previous simulation exercises of this type conducted by Ricardo (which in all cases have been run on vehicles more similar, in terms of vehicle weight, engine displacement and with use of fixed transmission ratios, to current conventional vehicles) have produced results suggesting that in all cases Highway fuel economy is better than that returned during the Urban cycle. This tendency is also confirmed in actual tests on real vehicles. Computer simulation runs with the vehicles used in this exercise, but fitted with larger capacity engines (retaining the same fuel consumption maps) and lower final drive ratios, so that shorter 0-50 mile/h acceleration times (∿12 s) and higher top speeds (∿80 mile/h) could be achieved indicated that Highway economy was then better than that returned over the Urban cycle. It therefore appears that the apparent anomaly, revealed in the present exercise is a real phenomenon in the particular cases of engine/transmission/vehicle concepts used.

The DI engine option displayed a fuel economy advantage of 7-11% over the IDI unit but was inferior in terms of exhaust emissions and vehicle performance.

With regard to exhaust emissions use of a 0.8 l, naturally aspirated, IDI engine in vehicle weighing 1000-1750 lb produced simulated exhaust emission levels within the 1982 standard (.41/3.4/1.0/0.6 g/mile HC/CO/NOx/particulates). At all vehicle weights above 1000 lb the predicted levels using the DI engine exceeded the standards for particulates and (at vehicle weights greater than 1500 lb) NOx. Predicted acceleration times for all engine/vehicle builds were rather poor; taking a 0-50 mile/h time of 25 seconds as the criterion of acceptability for vehicles of this type the IDI engine would appear to be acceptable for vehicles of up to 1750 lb while the DI unit appears to be feasible in vehicles up to 1500 lbs.

Apart from performance, fuel economy and exhaust emissions characteristics there are several other parameters of importance when assessing the suitability of an engine for use in a particular vehicle. The level of noise and vibration produced by diesel engines, particularly of DI configuration, is quite high; in two cylinder engines vibration problems are likely to be very pronounced and even the use of balancer shafts and special purpose engine mounts may not reduce the problem to acceptable levels especially in the light weight vehicles considered here.

5. CONCLUSIONS

Based on current knowledge of engine characteristics the results of this simulation exercise suggest that a naturally aspirated IDI diesel engine of 0.8 l could be an acceptable power unit with respect to acceleration time and exhaust emissions for light duty vehicles weighing up to 1750 lb. Above this weight vehicle performance and emissions would probably prove to be unacceptable.

A 0.8 l DI diesel engine could provide reasonable performance in vehicles up to 1500 lb but some reductions in emissions, especially particulates are necessary if U.S. requirements are to be satisfied.

For the 1000 lb vehicle predicted fuel economy over the FTP (Urban cycle) was 94 and 86 miles/US gall. (86 and 79 miles/US gall, Highway) for the DI and IDI engines respectively.

Some factors likely to have a considerable influence on engine/ vehicle acceptability, e.g. noise, vibration, cost, have not been addressed in this study.

6. REFERENCES

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TABLE 1

Characteristics of Vehicles Powered by Small Diesel Engines

	800 cc IDI Diesel Engine			800 cc DI Diesel Engine		
Vehicle Weight (lb)	Final Drive Ratio	Maximum Speed mile/h	0-50 mile/h time (sec)	Final Drive Ratio	Maximum Speed mile/h	0-50 mile/h time (sec)
1000	4.05	69.5	14.3	4.05	68.1	15.6
1250	4.20	67.4	17.5	4.20	66.1	19.5
1500	4.35	65.6	20.7	4.35	64.3	23.3
1750	4.50	63.9	24.9	4.50	62.5	27.7
2000	4.65	62.3	28.8	4.65	60.8	31.9

TABLE 2

Predicted Exhaust Emissions & Fuel Economy

Vehicle Weight (lb)	800 cc IDI Diesel Engine						800 cc DI Diesel Engine					
	FTP Exhaust Emissions g/mile				Fuel Economy mile/US gall		FTP Exhaust Emissions g/mile				Fuel Economy mile/US gall	
	HC	CO	NOx	Parti-culates	LA4	Highway	HC	CO	NOx	Parti-culates	LA4	Highway
1000	.11	.72	.57	.35	85.6	78.6	.23	.88	.77	.50	94.2	85.7
1250	.13	.88	.64	.42	75.0	70.4	.26	1.17	.86	.61	82.1	76.7
1500	.15	1.10	.73	.49	65.7	62.9	.29	1.53	.97	.71	71.9	68.6
1750	.17	1.31	.81	.57	58.2	56.0	.33	1.94	1.08	.82	63.0	61.5
2000	.19	1.52	.89	.62	52.3	50.2	.37	2.38	1.20	.92	55.9	55.7

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FIG. No. 1

Drg. No. D43791

Date FEB '81

ASSUMED MECHANICAL CVT PERFORMANCE CHARACTERISTICS

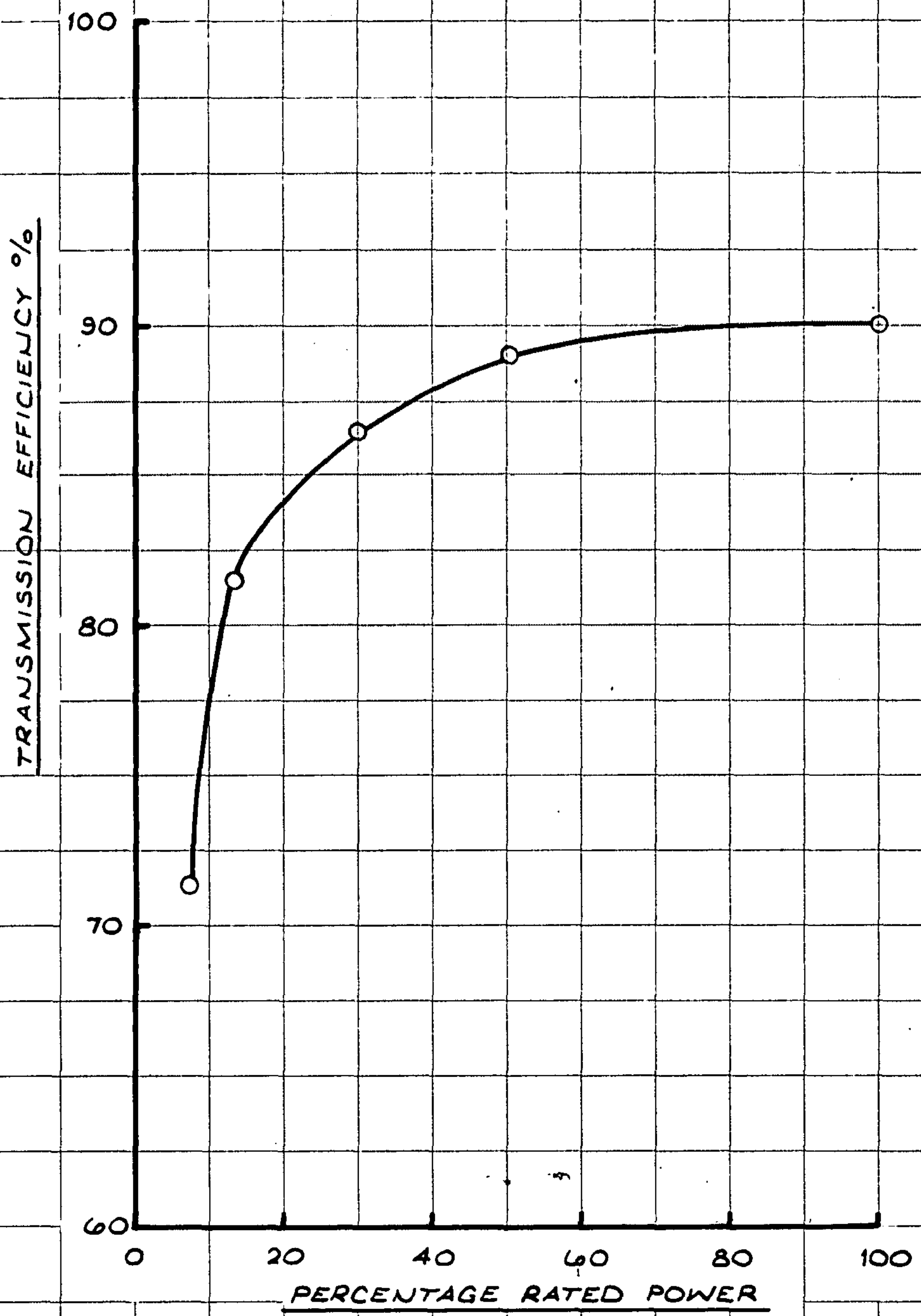

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FIG. No. 2
Drg. No. D 44492
Date 27 - 5 - 81

PREDICTED EXHAUST EMISSION LEVELS

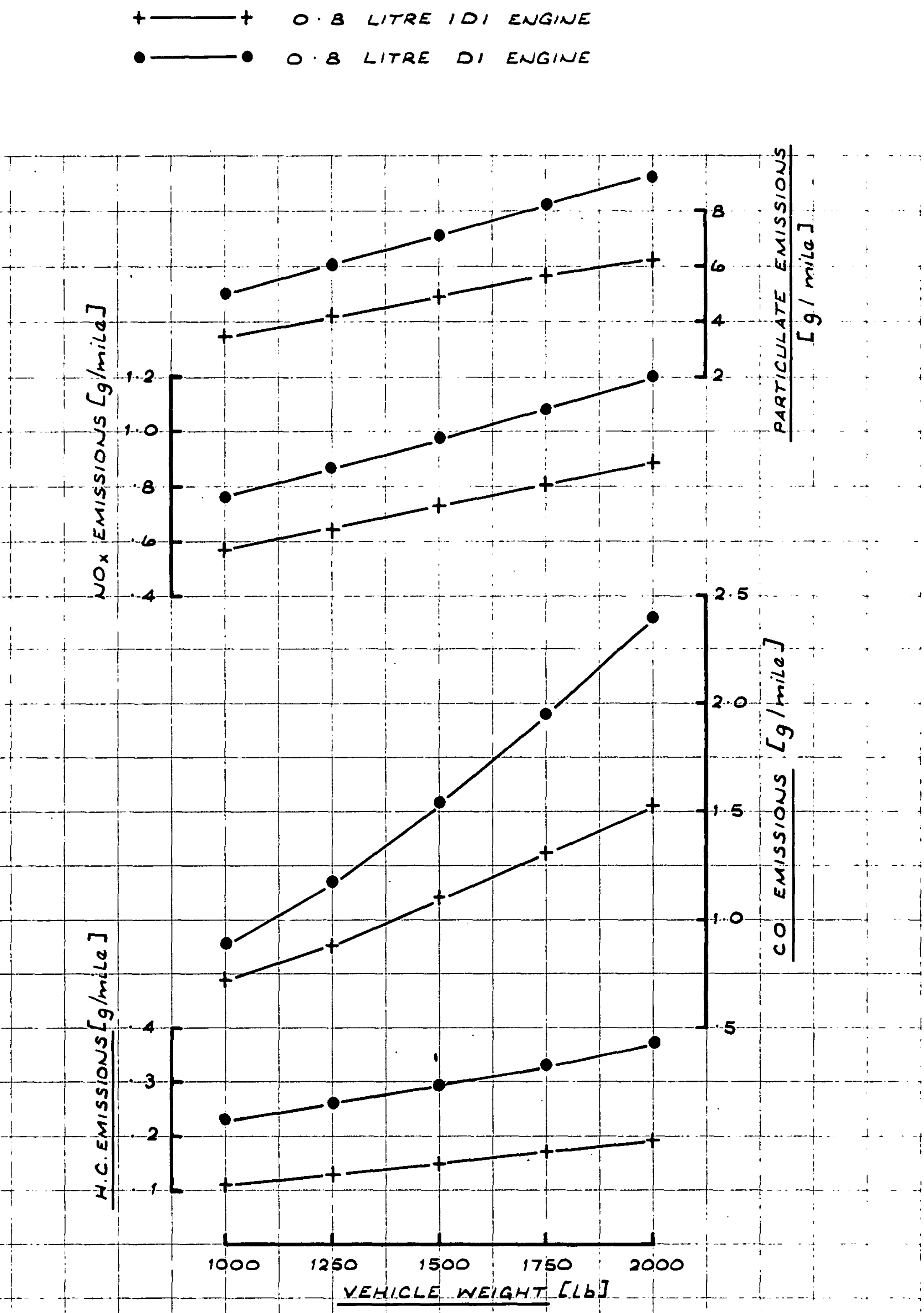

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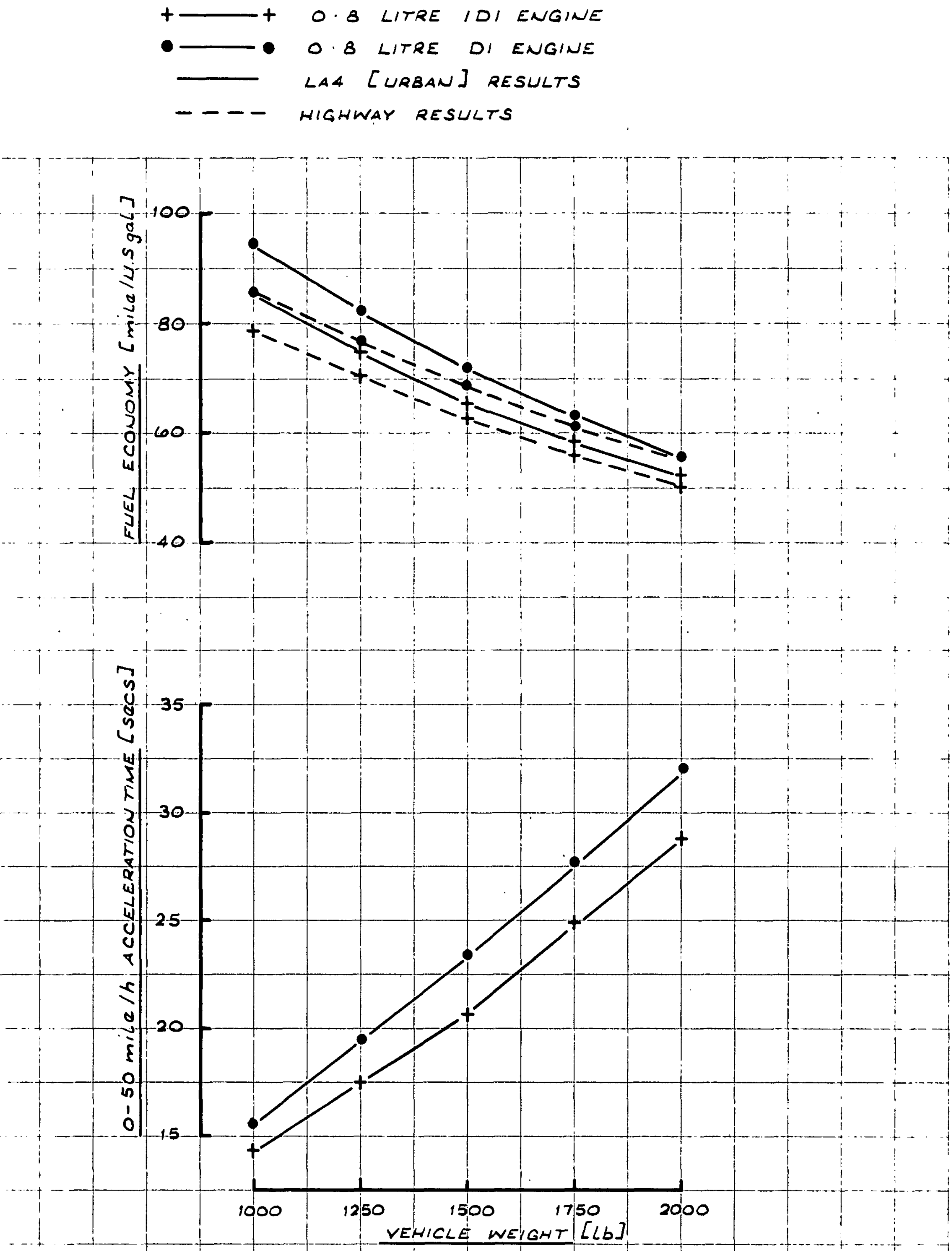
FIG. No. 3

Drg. No. D44493

Date 26-5-81

PREDICTED VEHICLE PERFORMANCE CHARACTERISTICS



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