TRANSPORT AND ROAD RESEARCH LABORATORY
Department of Transport

RESEARCH REPORT 287

THE EFFICIENCY OF AUTOMOTIVE EXHAUST CATALYSTS AND THE EFFECTS OF COMPONENT FAILURE

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Department of Transport

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1990

ISSN 0266-5247

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THE EFFICIENCY OF AUTOMOTIVE EXHAUST CATALYSTS AND THE EFFECTS OF COMPONENT FAILURE

ABSTRACT

Tests were carried out to discover how efficient automotive catalysts were after approximately 80 000 km of use and, by removing the catalysts from catalyst-equipped cars, to compare their raw emissions with those from non-catalyst equipped cars. Tests were also carried out to examine the effect on emissions of exhaust oxygen sensor malfunction and spark plug deterioration. Catalyst efficiencies ranged between 69 per cent and 88 per cent for hot start tests. Raw emissions of hydrocarbons and carbon monoxide from the catalyst controlled cars were lower than those from the non-catalyst car, while raw emissions of oxides of nitrogen were similar for all cars. When the exhaust sensors were disconnected, there was an immediate deterioration in the control of emissions from the three-way catalyst car; emissions from the lean-burn car with the oxidation catalyst showed little change. When one spark plug lead was disconnected there was a large increse in fuel consumption and emissions of hydrocarbons and carbon monoxide from both types of car. There was a large decrease in emissions of oxides of nitrogen from the three-way catalyst car, and little change in emissions of oxides of nitrogen from the lean-burn car.

1 INTRODUCTION

New legislation within the European Community (EC) significantly reduces the allowable exhaust emissions from cars. A study of the emissions from six medium sized (1.6 litre) cars was carried out as part of the process leading to the establishment of the new standards. A report on this study is in preparation. Two of the cars tested had lean-burn engines and oxidation catalysts and two were fitted with three-way catalysts. The other two cars had no special emissions control equipment and were manufactured to comply with current emission regulations (Council of European Communities, 1983). This study will be referred to as the 'main study'. It took place at a time when it was expected that limits for emissions from medium-size cars would be set at a level achievable by a variety of technical means. However, subsequent developments have lead to the adoption of new standards implying that all cars sold in the Community after 1992 will be fitted with three-way catalysts to control emissions. (Council of European Communities 1990). An additional feature of the most recent regulations is tht they include a provision for testing the durability of emissions control systems and evaporative emissions. Furthermore, the desire to ensure that emissions from vehicles in use do not exceed acceptable levels has prompted the consideration of periodic emission tests for vehicles in service.

The efficient operation of three-way catalysts depends on keeping the exhaust oxygen within a very narrow range by control of the air/fuel ratio of the mixture entering the engine. Precise fuelling is also necessary to enable lean-burn engines to operate effectively. If cars are to meet the exacting emission standards currently proposed, they will almost inevitably require an electronically controlled fuel injection system to provide this close control of mixture strength. Because of the dependency of their exhaust emissions on such precise engine management, there is a possibility that the emissions performance of catalyst equipped cars could be significantly worsened by malfunctions within the engine or its control system. Rates of emission from conventional European cars, with simple fuel and ignition systems, are also known to vary significantly because of maladjustment, but the potential deviation from the correct levels for catalyst equipped cars could well be greater. On any car, overfuelling causes increased emissions of carbon monoxide (CO) and hydrocarbons (HC) and reduced emissions of oxides of nitrogen (NOx): measurements by Potter and Savage (1986) on standard carburetted cars showed that CO emissions could increase by up to 400 per cent through normal drift of engine settings between routine services. Such variation with a three-way catalyst equipped car would be compounded by the effect on the catalyst efficiency of the changed exhaust composition: the oxygen deficiency of the exhaust would render the catalyst ineffective in oxidizing CO and HC, with the effect that the rates of emission would be no better than those from a poorly tuned uncontrolled car. The percentage change could be greater because of the very low level of emissions when the car was operating correctly.

Therefore, at the end of the main study, a series of further tests was carried out to discover how efficient the catalysts were after approximately 80 000 km of typical driving on public roads in Britain, to compare raw emissions with those from the non-catalyst cars and to examine the effects on emissions of failures within the engine management systems. Two possible failures were simulated: exhaust sensor malfunction and spark plug failure. The problems were examined in their most extreme cses by disconnection of the sensor or of one spark plug lead.

2 TEST PROCEDURE

Three of the cars used in the main study were used for these tests. Specifications of the cars are given in Table 1. Both the lean-burn and three-way catalyst cars were available only in the Japanese domestic market and were certified in accordance with Japanese emissions standards (OECD, 1988). The non-catalyst car was designed for sale in Europe and was certified to comply with EC Directive 83/351/EEC, (Council of European Communities, 1983).

Tests were carried out using a chassis dynamometer, a conventional constant volume sampler and standard gas analyzers (flame ionization for HC, chemiluminescence analyzer for NOx and infra-red analyzers for CO and carbon dioxide (CO_2)). Test conditions and, where appropriate, procedures, conformed as far as possible with those specified in EC regulations.

The maximum speed of the dynamometer was 100 km/h. Therefore, in order to extend the operating ranges of the engines on the dynamometer, some of the tests were carried out in both fifth and third gears.

2.1 CATALYST EFFICIENCY TESTS

The object of these tests was two-fold: to discover how efficient the catalysts were after approximately 80 000 km in use and to measure the raw emissions from the catalyst equipped cars for comparison with the non-catalyst car. Tests were carried out on the catalyst controlled cars before and after the removal of the catalysts, and on the non-catalyst car in its standard condition.

Two sets of tests were performed, hot and cold start tests over the ECE Regulation 15 cycle and steady speed tests as shown in Table 2.

The steady speed tests lasted 5 minutes and were preceded by a 5 minute conditioning period at the same speed; the tests were repeated four times for each car.

2.2 SYSTEM MALFUNCTION TESTS

In order to evaluate the effect on emissions of failures within the engine management system, tests were carried out with the catalyst equipped

Table 1

Vehicle specifications

	Carina SG	Carina ST	Corolla
Engine type	4A-ELU (Lean-burn)	4A-ELU (3 way cat)	4A-GE
Engine size (litre)	1.6	1.6	1.6
Power DIN kW	NA	NA	89 @ 6600 rpm
SAE net kW	73.5 @ 5600 rpm	73.5 @ 5600 rpm	86 @ 6600 rpm
Fuel consumption			
(l/100 km) ECE15	NA	NA	8.8
Japanese 10 mode	5.9	6.9	8.1
Fuel injection	Sequential	Parallel	Parallel
Compression ratio	9.3:1	9.0:1	10.0:1
Exhaust treatment	Oxidation catalyst	Three-way catalyst	None

Table 2

Steady speed tests

	5th gear			3rd gear		
Nominal speed (km/h)	60	80	100	30	50	70
Nominal RPM						
Three-way catalyst	1840	2460	3070	1480	2470	3450
Lean-burn	1640	2180	2730	1390	2320	3250
Non-catalyst car	2020	2690	3360	1620	2700	3780

cars operating in each of two failure modes. The first was with the exhaust oxygen sensor disconnected. The oxygen sensors were of two types. That fitted to the lean-burn car produced a voltage proportional to the exhaust oxygen content while that fitted to the three-way catalyst car was of the 'lambda sensor' type, indicating only the absence or presence of oxygen in the exhaust stream. In both cases, they formed part of the closed-loop engine control system that metered fuel in accordance with the power demand and the proportions of the air/fuel mixture as indicated by the exhaust sensor. Disconnecting the sensors enabled testing to take place to measure emissions without a closed loop control system. When feedback from the sensor was no longer available, control of the fuelling reverted to fixed settings stored in the engines' microprocessors and was not, therefore, able to compensate for deviations from optimum conditions resulting from wear or maladjustment.

The second failure mode was with one spark plug lead disconnected. This simulated a deficient spark plug or ignition system by removing the firing pulses completely from one cylinder.

Tests were performed over ECE Regulation 15 cycle from a hot start and at constant speeds of 60, 80 and 100 km/h in fifth gear. A set of reference tests was carried out first with each car in the standard condition. Because of the possibility of problems when running at high speeds with a plug lead discnnected, coolant temperatures were monitored carefully during these tests.

3 DISCUSSION

3.1 CATALYST EFFICIENCY TESTS

The mean results for the ECE15 tests for all types of car are shown in Table 3. The mean results for the steady speed tests are listed individually by type of car in Tables 4, 5 and 6. Figure 1 shows emissions of NOx, HC, CO and fuel consumption plotted against speed for the three-way catalyst car, with and without the catalyst. Similar graphs for the lean-burn car are shown in Figure 2. Figure 3 compares emissions from the non-catalyst car with those from the three-way catalyst and lean-burn cars without their catalysts.

Figure 4 shows the effect of air/fuel ratio on catalyst conversion efficiency (Ghandi 1987). Provided the air/fuel ratio remains between about 14.5:1 and 14.6:1, the catalyst will reduce NOx and oxidise HC and CO at not less than 80 per cent efficiency. For lean mixtures (air/fuel ratio > 14.6:1), the efficiency with which NOx is reduced falls rapidly and the catalyst becomes simply an oxidation catalyst. For rich mixtures, catalyst efficiency falls for all gases, but oxidation efficiency in particular is lower. It is possible to design catalysts to be particularly effective for either oxidation or reduction reactions by varying their relative contents of different precious metals. However, those used on both types of car in this study (lean-burn and three-way catalyst) were identical, so their different behaviour resulted solely from differing engine operating conditions.

Three-way catalyst systems are designed to operate in the narrow air/fuel ratio band in which

Table 3

ECE 15 test results (with and without catalysts)

	NOx (g/test)		HC (g/test)		CO (g/test)		FC (l/100 km)	
	cat	nc	cat	nc	cat	nc	cat	nc
THREE-WAY CATALYST								
cold start	4.81	8.97	3.77	9.36	32.0	47.6	11.3	11.6
hot start	3.38	9.10	1.82	8.84	11.1	30.7	9.8	10.0
LEAN-BURN								
cold start	8.19	8.71	6.24	11.05	22.9	29.8	10.4	10.2
hot start	7.15	8.58	2.47	11.05	1.8	9.6	8.9	9.0
NON-CATALYST								
cold start	—	11.83	—	25.09	—	100.6	—	12.9
hot start	—	12.22	—	32.24	—	49.7	—	10.1

Key: cat — with catalyst
nc — without catalyst
FC — fuel consumption

Table 4

Catalyst efficiency tests at steady speeds: three-way catalyst car

	NOx (g/km)		HC (g/km)		CO (g/km)		FC (l/100 km)	
gear/speed	cat	nc	cat	nc	cat	nc	cat	nc
5/60 km/h	0.42	1.32	0.07	0.55	0.25	3.60	4.86	4.77
5/80 km/h	0.46	1.99	0.10	0.52	0.73	3.41	5.68	5.56
5/100 km/h	1.16	3.06	0.10	0.53	0.56	3.70	6.46	6.46
3/30 km/h	0.36	1.30	0.15	0.81	0.49	2.10	5.97	5.92
3/50 km/h	0.35	1.35	0.09	0.59	0.60	3.71	6.19	6.20
3/70 km/h	0.83	2.68	0.08	0.54	0.53	4.32	6.48	6.57

Table 5

Catalyst efficiency tests at steady speeds: lean-burn car

	NOx (g/km)		HC (g/km)		CO (g/km)		FC (l/100 km)	
gear/speed	cat	nc	cat	nc	cat	nc	cat	nc
5/60 km/h	1.33	1.42	0.19	0.57	0.05	0.47	4.26	4.17
5/80 km/h	2.78	2.65	0.17	0.50	0.08	0.49	4.99	4.81
5/100 km/h	3.58	3.89	0.14	0.38	0.10	0.52	5.84	5.63
3/30 km/h	0.88	1.16	0.30	0.96	0.04	0.72	5.23	5.30
3/50 km/h	2.00	2.08	0.18	0.60	0.08	0.73	5.49	5.52
3/70 km/h	2.03	1.82	0.14	0.45	0.08	0.79	5.74	5.67

Table 6

Catalyst efficiency tests at steady speeds: non-catalyst car

	NOx (g/km)		HC (g/km)		CO (g/km)		FC (l/100 km)	
gear/speed	cat	nc	cat	nc	cat	nc	cat	nc
5/60 km/h	—	2.96	—	0.64	—	7.24	—	5.18
5/80 km/h	—	3.04	—	0.74	—	8.14	—	5.56
5/100 km/h	—	3.55	—	0.99	—	14.78	—	6.59
3/30 km/h	—	1.55	—	1.27	—	2.33	—	5.97
3/50 km/h	—	2.56	—	0.79	—	1.56	—	6.13
3/70 km/h	—	2.77	—	1.05	—	10.25	—	6.40

See Table 3 for key to abbreviations

conversion efficiencies for all three pollutants are high. Lean-burn engines, on the other hand, use a weak mixture and, in consequence, no catalytic reduction of NOx is possible. However, as shown in Figure 5 (Gruden, 1985), lean mixtures produce lower NOx levels in the exhaust. Catalysts effectively promote oxidation reactions with lean mixtures so that CO (which is also inherently low) and HC levels may be catalytically controlled.

In addition to the appropriate exhaust gas composition, produced by close control of the air/fuel ratio, it is also necessary for the temperature of the catalyst to be sufficiently high for effective operation.

The combined effects of engine operating conditions and catalyst efficiency are shown clearly by the results of these tests.

3.1.1 Three-way catalyst

The effect of warmup on the catalyst efficiency is shown by the tests over the ECE 15 cycle, which

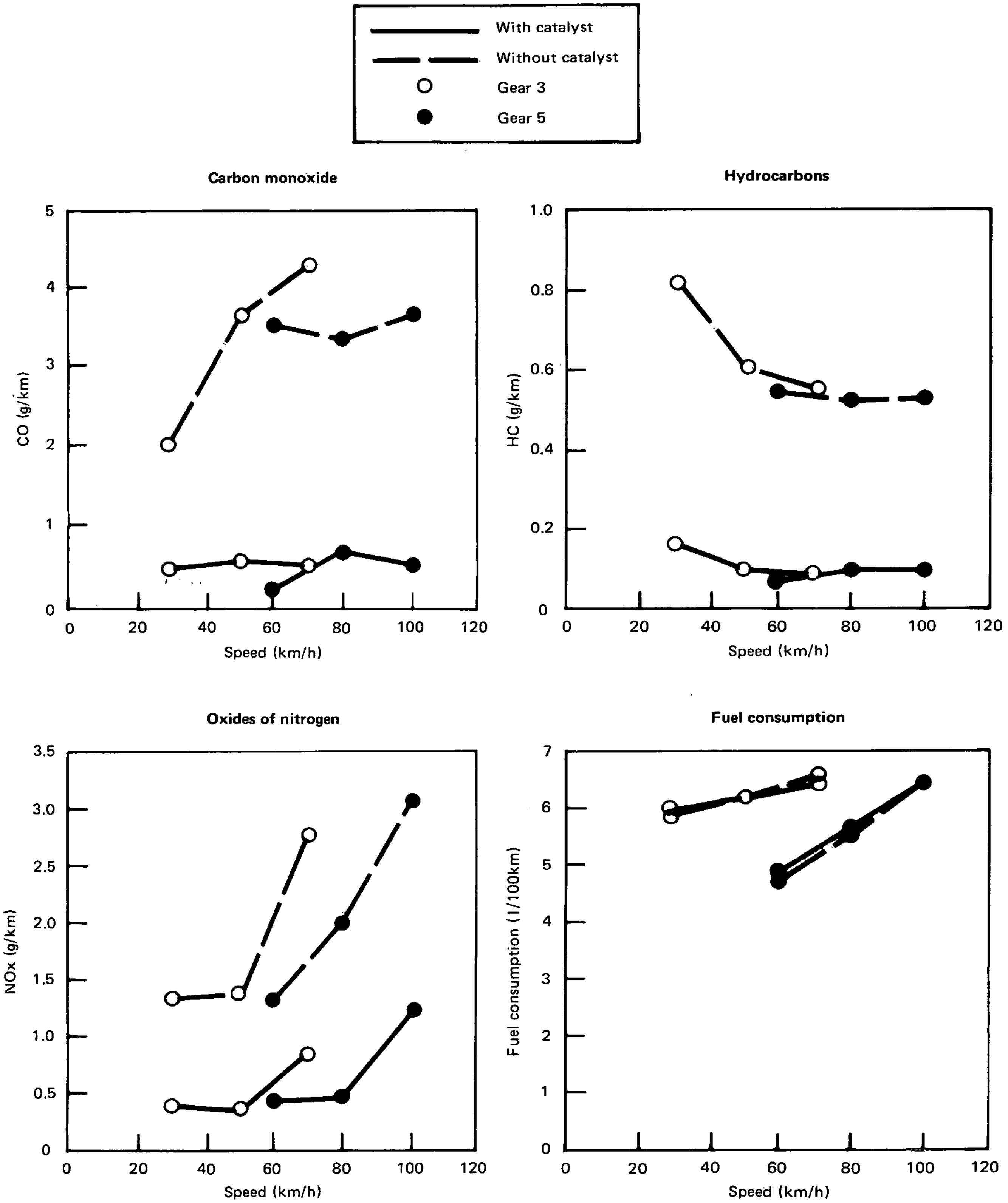

Fig.1 Effect of catalyst removal: three-way catalyst car

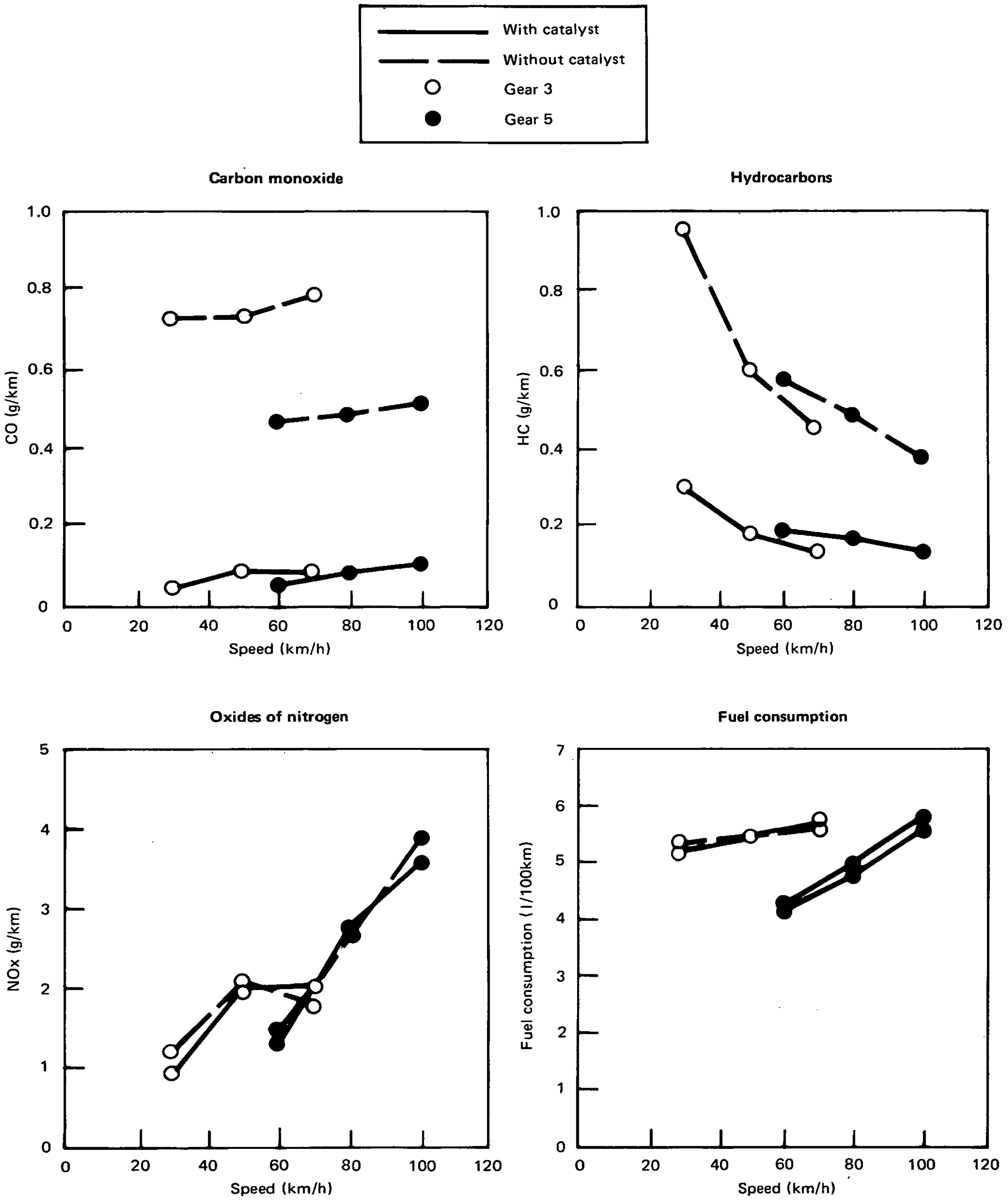

Fig.2 Effect of catalyst removal: lean-burn car

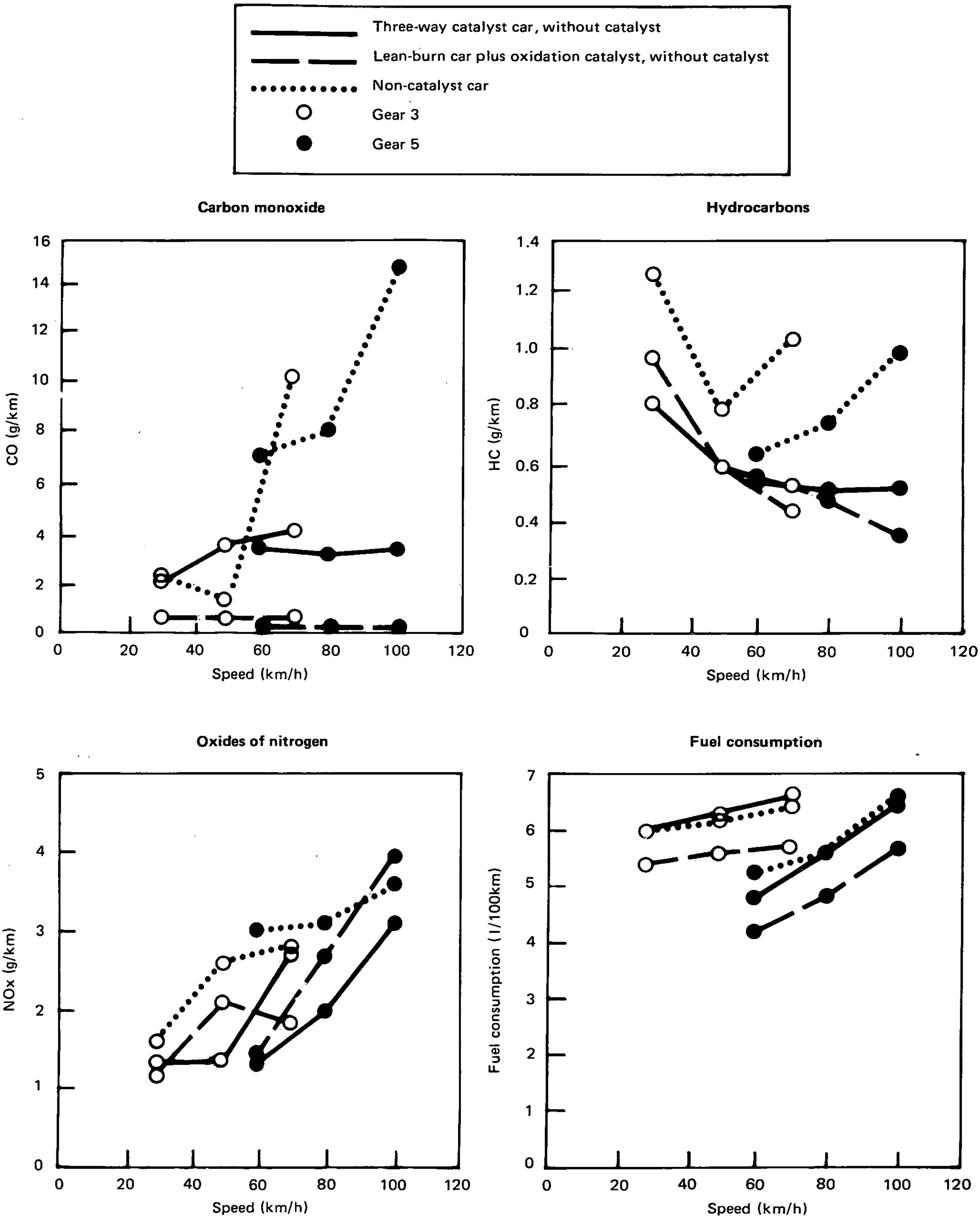

Fig.3 Comparison of untreated emissions at steady speeds

were carried out from both cold and hot starts (Table 3). The efficiency of the catalyst is measured in each case over the complete ECE 15 test, which represents 4 km of driving in urban conditions. Because of the time needed for the catalyst to reach its operating temperature, the cold start tests gave much lower efficiencies than the hot start tests with CO conversion showing the lowest efficiency of 33 per cent compared with 64 per cent when fully warmed up. Equivalent results for NOx were 46 per cent (cold) and 63 per cent (hot), and for HC, 60 per cent (cold) and 79 per cent (hot). Figure 1 shows that emissions of NOx, HC and CO were reduced considerably by the catalyst for all steady speed tests, showing, therefore, that the engine management system was effectively maintaining an air/fuel ratio close to stoichiometric. Average catalyst efficiencies during these tests, which were all started with fully warmed up engines, were approximately 69 per cent for NOx and 84 per cent for HC and CO. The fuel consumption showed no significant variation when the catalyst was removed. Therefore, the presence of the catalyst in the exhaust had no physical effect, such as increasing the exhaust back pressure and hence reducing the power. The effect on fuel consumption of driving in third or fifth gear was, however, very marked.

3.1.2 Lean-burn engine plus oxidation catalyst

The effect of warmup on conversion efficiency over the ECE 15 test was even more marked with the lean-burn car with cold start efficiencies of 23 per cent for CO and 44 per cent for HC compared with about 80 per cent in each case when fully warmed up. As expected, NOx conversion efficiencies were low, at about 6 per cent (cold) and 17 per cent (hot). That there was some, albeit limited, conversion indicates that the engine did not operate in the lean air/fuel ratio region at all times during the ECE 15 cycle. Figure 2 shows that emissions of NOx with and without the catalyst were very similar for all steady speeds. The lean-burn engine was designed to run at an air/fuel ratio as high as 21.5:1 in steady speed conditions (whereas there is some fuel enrichment to enable satisfactory performance during the idling and transient operations that are part of the ECE 15 cycle) (Matsushita et al, 1985), so no catalytic reduction in NOx would be expected. The average effect of the catalyst on HC emissions at steady speeds was to reduce them by approximately 69 per cent. Even without the catalyst the emissions of CO from the lean-burn engine were low, and the effect of the catalyst was a mean reduction of 88 per cent, resulting in very low overall emissions. Again the fuel consumption figures show no significant variation when the catalyst was removed.

3.1.3 Comparison with the non-catalyst car

If catalysts fitted to cars fail totally then the emissions will revert to those characteristic of the cars' engine type. Under those circumstances, it is possible that rates of emission could be higher than from cars designed to operate without catalysts. Gruden (1985) has shown, for example, that the air/fuel ratio strongly influences the formation of pollutants in the engine (Figure 5);

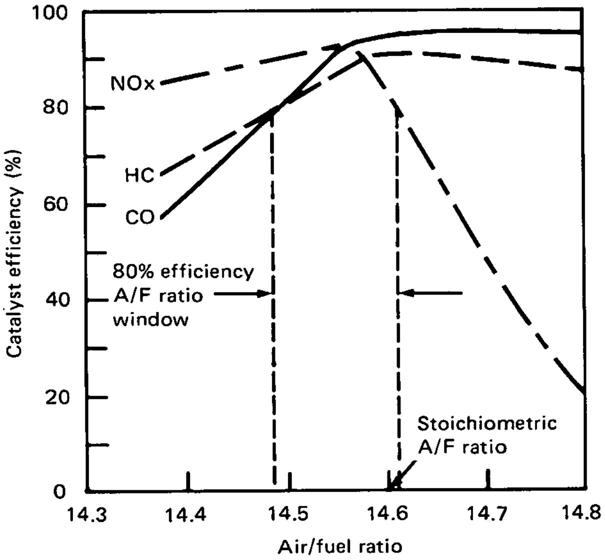

Fig.4 Conversion of NOx, CO and HC for a three-way catalyst as a function of air/fuel ratio (Ghandi, 1987)

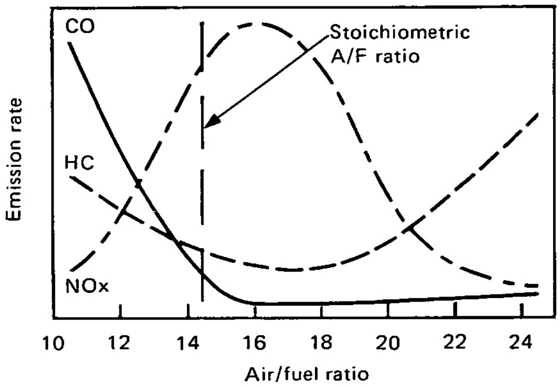

Fig.5 Effect of air/fuel ratio on emissions (Gruden, 1985)

Ghandi (1987) has shown that three-way catalyst cars are constrained to operate in a very narrow air/fuel ratio range (Figure 4). Where that constraint is removed, it is possible to operate in an air/fuel ratio region where pollutant formation is lower. This is a fundamental principle for the design of lean-burn engines, but it is also true, to a lesser extent, for more conventional engines. Figure 3 illustrates the emissions at steady speeds from both types of catalyst equipped car when tested without catalysts and, for comparison, those from the non-catalyst car.

NOx emissions from both cars normally equipped with catalysts were similar. Surprisingly, the engine of the three-way catalyst car did not produce more NOx than the lean-burn engine. Both produced less than the engine of the non catalyst car. Without catalysts the lean-burn and three-way catalyst cars also produced similar emissions of HC and their emissions were again consistently lower than those from the non-catalyst car. Emissions of CO from the lean-burn engine were very low compared with the other two cars and, once again, emissions from the non-catalyst car were greatest. Fuel consumption figures for the three-way catalyst and non-catalyst cars were very similar, while the lean-burn car showed an overall reduction in fuel consumption of about 1 l/100 km compared with the other two cars.

With the exception of the unexpectedly high NOx emissions from the lean-burn engine, these results are consistent with the engine to engine differences between the cars. The non-catalyst car operated at higher engine speeds and a higher compression ratio than the others, which would tend to increase peak engine temperatures on which the formation of NOx depends. This engine also developed most power, implying generally higher fuelling rates that would increase CO and HC formation. Low CO emission and fuel consumption rates for the lean-burn engine resulted from lean mixture operation.

3.2 SYSTEM MALFUNCTION TESTS

In addition to the tests in which faults were simulated, tests were carried out in the standard condition for comparison. In general these reference tests gave emission and fuel consumption results that were similar to those from other tests carried out at about the same time, both from the main study and from the catalyst efficiency tests. There were, however, two exceptions, with one test for each car giving an uncharacteristic fuel consumption rate (calculated by the carbon balance method). For the three-way catalyst car, the fuel consumption at 80 km/h was significantly lower (4.8 l/100 km compared with approximately 5.6 l/100 km) and for the lean-burn car at 100 km/h, 4.7 l/100 km was measured, compared with approximately 5.6 l/100 km typical of other tests. As it was possible to do only one test at each speed because of time constraints, these two non-typical values have been discounted. The values used are those obtained from the reference tests for catalyst efficiency. These tests were carried out in the same month as the system malfunction tests.

The results for the ECE 15 tests for both types of car are shown in Table 7 and the results for the steady speed tests are given in Tables 8 and 9 and Figures 6 and 7.

3.2.1 Disconnection of oxygen sensor

Disconnection of the exhaust oxygen sensor on the lean-burn and three-way catalyst cars prevents the engine management system from operating in a closed-loop manner by removing the necessary information on air/fuel ratio. Under these circumstances, the systems revert to a fall-back mode which relies on stored information. The effect on emissions will obviously depend on the deviation of actual conditions from the stored default values. Such deviations will in turn depend on the precision with which the engine was originally calibrated and on any temporary changes

Table 7

ECE 15 (hot start) test results for system malfunction

	NOx (g/km)	HC (g/km)	CO (g/km)	Fuel cons (l/100 km)
Three-way catalyst				
Reference	0.49	0.84	2.11	9.41
Sensor disconnected	1.05	0.43	4.15	9.80
Plug lead removed	0.24	8.46	36.38	14.28
Lean-burn + oxy cat				
Reference	1.53	0.56	0.44	9.23
Sensor disconnected	1.54	0.61	0.80	9.33
Plug lead removed	2.03	5.43	1.14	11.08

Table 8

Effect of system malfunction at steady speeds—three-way catalyst car

	NOx (g/km)	HC (g/km)	CO (g/km)	Fuel cons (l/100 km)
60 km/h				
Reference	0.596	0.056	0.236	4.77
Sensor disconnected	0.061	0.226	0.950	4.80
Plug lead removed	0.087	3.181	10.700	6.70
80 km/h				
Reference	0.622	0.051	0.716	5.68*
Sensor disconnected	1.794	0.114	0.093	5.49
Plug lead removed	0.117	3.329	23.738	8.15
100 km/h				
Reference	1.302	0.049	0.483	6.29
Sensor disconnected	0.365	0.313	4.586	6.29
Plug lead removed	N/A	N/A	N/A	N/A

* = Substitute value for non-typical result

Table 9

Effect of system malfunction at steady speeds—lean-burn car

Steady speeds	NOx (g/km)	HC (g/km)	CO (g/km)	Fuel cons (l/100 km)
60 km/h				
Reference	1.080	0.171	0.055	4.01
Sensor disconnected	0.849	0.181	0.042	4.14
Plug lead removed	0.844	1.711	0.740	4.96
80 km/h				
Reference	2.784	0.179	0.103	4.95
Sensor disconnected	2.284	0.167	0.115	5.02
Plug lead removed	2.188	1.986	3.842	7.11
100 km/h				
Reference	3.517	0.113	0.073	5.84*
Sensor disconnected	3.147	0.129	0.118	5.78
Plug lead removed	N/A	N/A	N/A	N/A

* = Substitute value for non-typical result

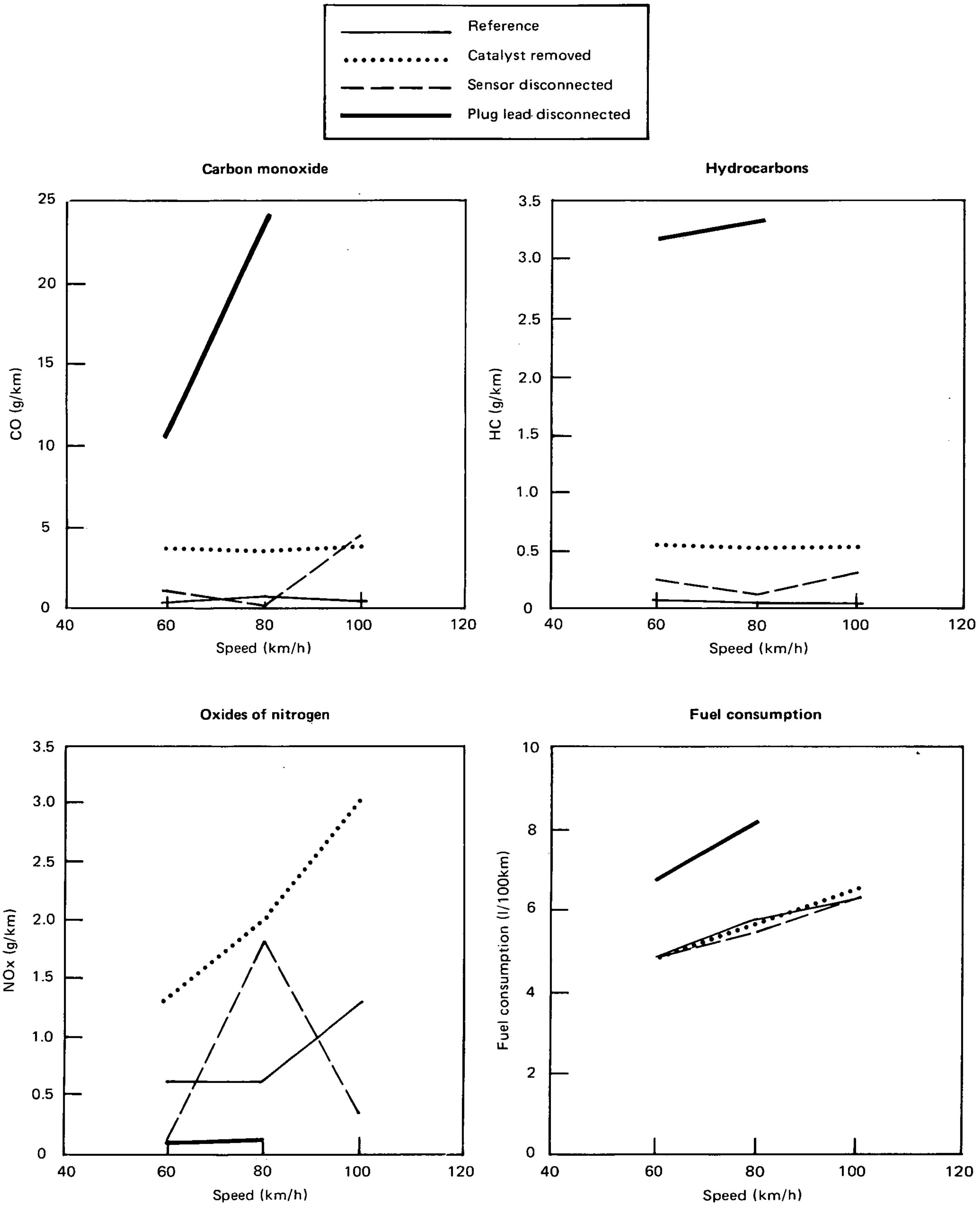

Fig.6 Effect of system malfunction on the three-way catalyst car

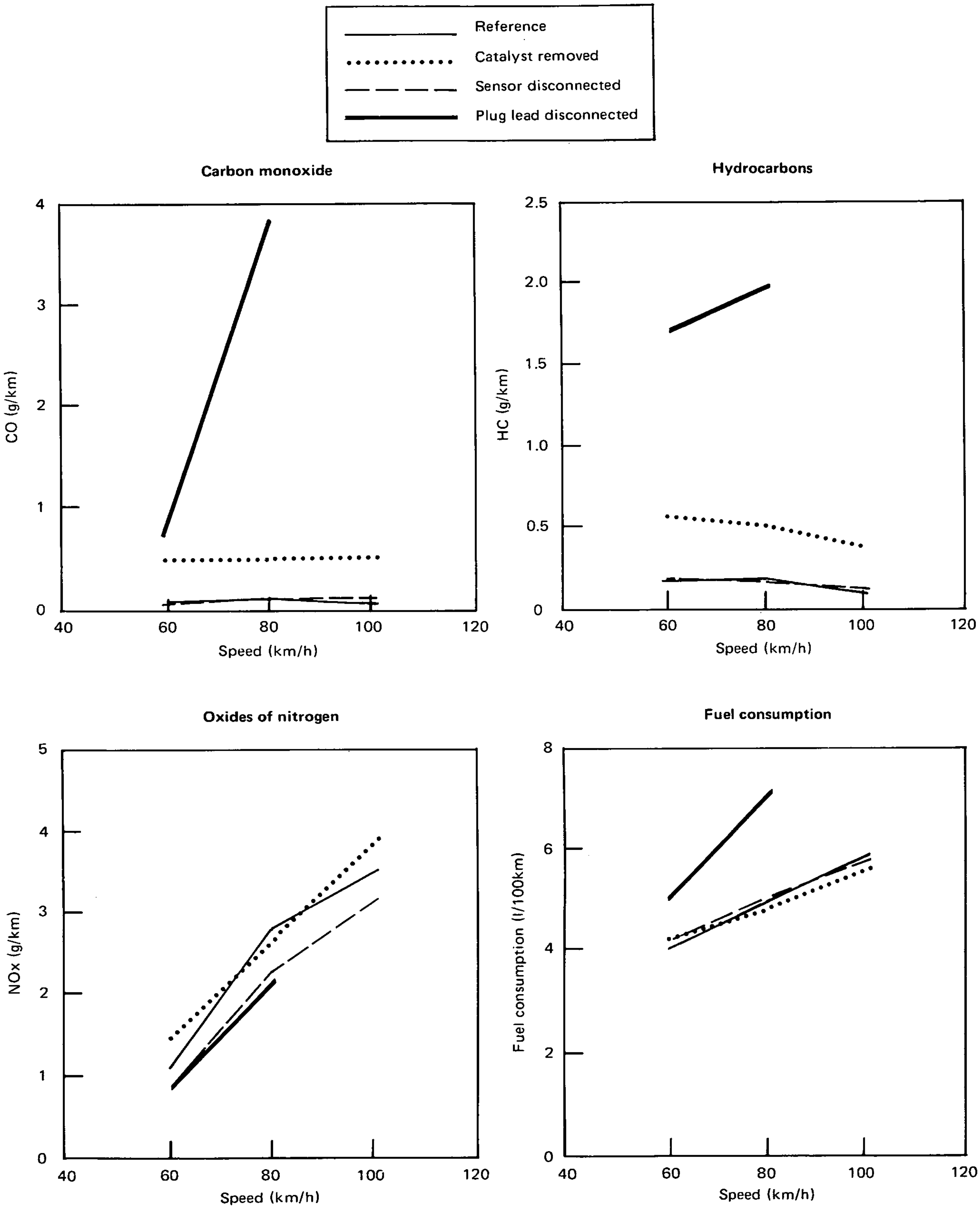

Fig.7 Effect of system malfunction on the lean-burn car

in setting due to maladjustments or permanent changes caused by wear or deterioration of the engine. The tests discussed here were carried out during the course of one day for each car and show, therefore, the results of one particular engine condition that may not represent the range of engine states possible over a longer time period. They were, however, carried out after the cars had been used for approximately 80 000 km, so that they should assess the potential for long-term engine deterioration.

At low and high speeds (ECE 15, 60 and 100 km/h), the three-way catalyst car showed lower than normal emissions of NOx and higher HC and CO, as would result from operating with a fuel rich mixture. At 80 km/h the reverse was observed. Although in absolute terms the changes in emissions were not large, nevertheless there was an apparent decrease in the accuracy of the control system. The effect on fuel consumption was minimal, indicating that exhaust composition is more sensitive than fuel consumption rates to relatively small changes in mixture strength. A similar result was seen for more conventional cars whose emissions and consumption were measured before and after tuning (Williams and Everett, 1983). They found that correctly tuning 64 cars had the average effect of reducing CO emissions by 36 per cent, HC emissions by 14 per cent and increasing NOx emissions by 19 per cent, but that fuel consumption was only reduced by 3 per cent.

Disconnecting the lean-burn sensor produced very little change in emissions and consumption. Emissions of NOx were slightly reduced but CO, HC and fuel consumption did not vary. Although the lean-burn sensor is used for feed back control by the engine management system it is not the primary reference as is the case for the lambda sensor of the three-way catalyst car. There is additionally a program within the electronic control unit (ECU) that calculates the target value for air/fuel ratio from the engine speed and intake manifold pressure. This target ratio is compared with the signal from the lean-burn sensor and the fuel injection quantity is adjusted according to this comparison. Without the signal from the sensor, the engine will still operate in accordance with the fuelling regime calculated by the ECU. The system is described more fully by Matsushita et al [1985]. The more limited effects may also result from the basic air/fuel ratio region in which the lean-burn engine operated. Figure 5 shows that deviations near to the stoichiometric ratio will result in changes in emissions, particularly for CO and NOx, that are greater than those caused by deviations in the lean mixture region.

3.2.2 Disconnection of spark plug lead

When a plug lead was removed the effect was dramatic and immediate on both cars because quantities of unburnt fuel and oxygen passed through the catalyst. This is of course a very serious type of malfunction but it is not uncommon, especially in older engines, to have some form of misfiring, and removal of a spark plug lead represents the most extreme version of this problem. For each car, HC emissions increased by very large amounts: they were effectively passing 25 per cent of the fuel straight through the engine. For the three-way catalyst car CO emissions increased greatly and NOx emissions reduced significantly as the control system was operating with abnormally rich air/fuel mixtures. For the lean-burn car the large increase in CO and the relatively small decrease in NOx suggests that its control system responded to the defect by changing the air/fuel ratio from a weak to a rich setting, whic promoted the formation of a similar amount of NOx but more CO. It proved impossible to test the cars at speeds over 80 km/h because of overheating of the catalysts. The fuel not burnt in the engine was burnt in the catalysts, which are in any case heated by the chemical reactions that they cause. Fuel consumption also increased significantly since a quarter of the fuel used was producing no power from the engines.

4 CONCLUSIONS

1. Exhaust emission measurements were made on three types of car: a three-way catalyst equipped car, a car with a lean-burn engine and oxidation catalyst and a car with a modern engine management system but with no special emission control system.

2. After being driven about 80 000 km on public roads in Britain, the efficiencies of the two exhaust catalysts ranged between 69 per cent and 88 per cent for hot start tests. For the three-way catalyst the average efficiencies during hot start tests were 69 per cent for NOx and 84 per cent for HC and CO. For the oxidation catalyst fitted to the lean-burn car, the average efficiencies were 69 per cent for HC and 88 per cent for CO.

3. There was no effect on fuel consumption when the catalysts were removed.

4. A comparison of untreated emissions from the three types of car was made, by removing the catalysts from the cars that were normally fitted with them. With the catalysts removed:

   a) emissions of NOx were similar for all cars

   b) emissions of HC from the three-way catalyst and lean-burn cars were consistently lower than those from the non-catalyst car

c) emissions of CO from the three-way catalyst car were lower than those from the non-catalyst car and those from the lean-burn car were extremely low.

5. When the lambda sensor of the three-way catalyst car was disconnected, there was significant change in the level of emissions. At some speeds HC and CO increased while NOx reduced, while at other speeds the reverse occurred. Emissions from the lean-burn plus oxidation catalyst car showed little change when the lean-burn sensor was disconnected.
6. When one spark plug lead was disconnected from the catalyst controlled cars, there was a very large increase in fuel consumption and emissions of HC and CO. There was a large decrease in emissions of NOx from the three-way catalyst car, but little change in emissions of NOx from the lean-burn car.

5 ACKNOWLEDGEMENTS

The work described in this report was carried out in Vehicles and Environment Division of Vehicles Group at TRRL.

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Printed in the United Kingdom for HMSO
Dd8222792 10/90 C4 G476 10170