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Department of the Environment
Department of Transport

TRRL SUPPLEMENTARY REPORT 822

THE INFLUENCE OF COOL ENGINES ON CAR FUEL CONSUMPTION

by

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Crowthorne, Berkshire
1983

ISSN 0305 - 1315

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THE INFLUENCE OF COOL ENGINES ON CAR FUEL CONSUMPTION

ABSTRACT

A national sample of car diaries, collected with the National Travel Survey in 1978–79, has made it possible to make a new estimate of the effect of cool engines on fuel consumption. For the first time it has been possible to make a detailed allowance for the effect of trips which start with the engine already warm.

The Report concludes that the extra fuel used, because engines are not fully warm at all times, is roughly one third of the present national consumption by cars.

1. INTRODUCTION

It is well known that engines consume more fuel when they are cold than when they are fully warmed up, and several authors have given examples of the way in which fuel consumption decreases from the start of a journey (eg. Blackmore and Thomas 1977, Waters and Laker 1980, Everall and Northrop 1970). Two of these references went on to attempt an estimate of the national consequences in the UK, but they were unable to allow properly for the pattern of journeys. New information about journeys has now become available, so a more realistic calculation has been attempted in this Report. The results suggest an order of magnitude for the importance of cold starts in national fuel consumption.

2. METHOD

Fuel consumption varies substantially with engine temperature, and car engines take quite a long time to cool down after use; so the amount of extra fuel used because of cold engines depends on the time intervals between trips as well as on the length of individual trips. Recently, vehicle diaries have become available which give information about these time intervals and allow a better calculation of the extra fuel. However, it remains necessary to make many assumptions – about the rate at which engines cool down, the rate at which they warm up again, and the way in which fuel consumption varies with engine temperature – because very little systematic information appears to have been published. In this Report, these assumptions (described below) have been combined with time sequence information from the diaries to yield an estimate of the extra fuel used because of cold engines.

A set of about 5500 vehicle diaries were collected at the same time as the National Travel Survey (covering the whole of Great Britain) in 1978–79. A subset of 978 of these diaries have been used for the analysis. Each diary records the distance travelled, and the start and finish time, of each trip by a given vehicle over a period of a week. The weeks in the subset are fairly uniformly distributed across the year and across the country, and leading characteristics of the subset have been shown not to be substantially different from the original sample.

For each vehicle diary, an engine temperature history has been inferred for the week, using oil temperature as an indicator. Beginning after a long interval between trips (to be sure that the engine is cold at the start) oil temperature is assumed to increase with distance according to the curve in Figure 1. This curve is a smoothed version of the measured behaviour of a Saab 95 car, reported in Odsell 1980. After the end of a journey, the temperature is assumed to drop again according to an exponential law with a time constant of 160 minutes; ie. it takes 8 hours to cool from maximum to 5^{o}C above ambient temperature. Ambient temperature was not known exactly; the mean monthly air temperature for the month of the trip (from Table 79, Department of Energy 1982) was used as a first order approximation.

Fuel consumed as a function of distance from a cold start is estimated using the straight-line approximation in Figure 2. The warm-up period is represented by a uniform reduction in consumption with distance, beginning at about 3.4 times the fully-warm value and declining to reach fully warm at 8 km (5 miles). Figure 2 also shows the evidence on which this approximation is based, which is the instantaneous consumption recorded at TRRL by a VW Golf car travelling at 64 kph (40 mph). (This measurement was taken during the work reported in Pearce and Waters 1980). Figure 2 was not adjusted to allow for the effect of ambient temperature; for the present purpose that merely implies an assumption that the shape of the curve does not change significantly with temperature; the absolute level of consumption is not used in the calculation.

The calculation proceeded in several stages. It first derived an estimate of the engine temperature at the start of each trip, using the warm-up and cool-down assumptions already described. The amount by which this temperature exceeded ambient was interpreted as an 'equivalent distance already travelled' (E), using Figure 1. The relative fuel consumption curve (Figure 2) was then integrated from E to E+T, where T is the trip length, and the result was summed over all trips by that vehicle in the week that records were kept. Finally, the answer was divided by the total length of the trips by that vehicle, to yield a factor which represents the amount by which actual fuel use exceeded that which would have been experienced if the engine had been fully warm at all times.

3. RESULTS

3.1 National averages

On the above basis, the extra fuel used was found to be 45 per cent. There were 17526 trips covering a total of 129,796 miles included in the diaries used. 36 per cent of the miles were travelled with the engine not fully warmed up.

As a guide to the significance of the underlying assumptions, the calculation was repeated twice. Firstly, the cool-down time constant was reduced from 160 minutes to 120 minutes (about 6¼ hours to cool to $5^{o}C$ above ambient). With this setting, the extra fuel was deduced to be three percentage points higher at 48 per cent.

Secondly, the fuel consumption curve shown in Figure 3 was used, for which the speed was 48 kph (from Figure 4, Reference 6). This case is likely to provide an upper limit to the amount of extra fuel, since it was done at low engine speed in top gear and therefore the engine took a particularly long time to warm up and was working relatively inefficiently; in fact, the engine was not fully warmed up until the car had travelled 22 km, instead of 8 km in the basic case. Using Figure 3 (and a time constant of 160 minutes) the extra fuel calculated was 55 per cent; in this case, only 27 per cent of the miles were travelled with the engine fully warmed up.

3.2 Individual experience

The importance of cold starts to individuals has also been investigated. Table 1 shows the number of vehicles which experienced the given percentage of cool running over the whole week ('cool' being defined as 'less than completely warmed up'.) Figure 2 was used, with a time constant of 160 minutes.

This table must be used with care; other evidence within the original set of diaries shows that many vehicles differ substantially in their pattern of use from week to week. Thus it is probable that some of the 69 vehicles in the 100 per cent cell of the table would move down to say the 80–90 per cent cell – or lower – if a period longer than a week was analysed. Nevertheless the number of individuals whose vehicles do all or nearly all their travelling 'cool' is quite significant; for them the 'cool' fuel consumption is much more important than the national average might imply.

TABLE 1

Distance run 'cool'

Distance run 'cool' (%)	Vehicles with given % of 'cool' running	
	Number	%
0– 9	20	2
10–19	90	9
20–29	105	11
30–39	152	16
40–49	137	14
50–59	90	9
60–69	86	9
70–79	69	7
80–89	63	6
90–99	68	9
100	69	9
No trips at all	29	3
TOTAL	978	100

3.3 Trip distributions

The value of the car diaries lies mainly in the information they contain about sequences of trips. Unfortunately such information is difficult to tabulate usefully, since the process of tabulation automatically destroys most of the evidence about linked sequences. Just one table (Table 2) seems worth displaying. It shows the way in which trip

TABLE 2

Trip length versus prior interval

Number of trips with:

Trip distance (miles)	Prior interval (mins) <5	5–15	15–30	30–60	60–120	120–240	240–480	>480	Total
⩽1	256	385	266	419	419	451	306	843	3345
2	165	197	221	334	375	364	221	729	2606
3	106	154	146	256	303	345	200	726	2236
4	59	81	96	173	232	232	152	515	1540
5	45	57	74	132	169	198	124	521	1320
6	32	47	47	105	132	139	84	372	958
7– 8	45	53	68	121	183	230	135	668	1503
9–10	21	31	36	68	132	141	94	444	967
11–15	27	50	54	97	148	169	153	705	1403
16–20	15	17	15	45	61	94	59	272	578
>20	19	26	45	66	117	147	143	507	1070
Total	790	1098	1068	1816	2271	2510	1671	6302	17526
average (miles)	4.1	4.3	5.3	5.6	6.8	6.8	8.7	9.4	overall 7.4

length is associated with the immediately preceeding trip interval. Each element of the table indicates the total number of trips having the named combination of trip length and time interval preceeding the trip, so that the table allows us to gain some idea how likely it is that (for example) long trips always follow short gaps between trips. In the outcome, it is striking that the average length of trips following short intervals is only 4.1 miles. Thus it seems there is a tendency for short journeys to be part of a linked sequence and the easy assumption that short journeys have cool engines is too sweeping. Although the trend of the average trip lengths is clear, the body of the table clearly shows that there is much variability in the detail.

4. DISCUSSION

From these results, it seems reasonable to deduce that the excess fuel use due to running with incompletely warm engines is in the range from about 40 per cent to about 60 per cent. In other words, cold starts and cool running are responsible for roughly a third of national private transport fuel consumption.

The method used to make this estimate is clearly imperfect, because so many assumptions were made. For example, fuel consumption for a single vehicle at a single speed under only a limited range of ambient temperatures has been used as a representative of all vehicles. Another vehicle might have been more representative. Indeed, perhaps more than one size of vehicle should have been used if, for example, short jorneys are particularly the province of small vehicles. Then again, oil temperature has been used as the indicator of all the temperature changes which affect fuel consumption, when it is only one of them; and yet again, a very arbitrary law has been assumed for the rate at which engines cool down.

From the calculations, it appears that uncertainties in the fuel consumption curve and the warm-up curve are more likely to be significant than the cool-down assumptions. In particular, the use of a fuel consumption curve based on a car using an automatic choke is debateable, even though automatic chokes have recently become much more common in the UK. Moreover the fuel consumption curve is most imprecise in the most critical region, the first 2 km, though in unpublished tests at TRRL another car with an automatic choke, an Escort, has given results similar to the Golf. Everall 1970 made an estimate that the extra fuel use was only about 10 per cent, much lower than the present calculation. It may be that these uncertainties are the most likely cause of the difference in estimates, though there are other possibilities (for example, that "hot" engine economy has improved to a greater extent than cold over the years).

The present work arose as a by-product of another use of the NTS car diaries, and it has not yet been possible to follow up the explanation of these differences. It seems highly desirable that more information should be gathered (especially on the variation of fuel consumption from car to car, and on the influence of automatic chokes), and that the calculations should be repeated on a firmer foundation.

Nevertheless, even with the present shortcomings of the evaluation, it is clear that cold running is an important factor in determining national car fuel consumption.

5. CONCLUSIONS

1. On the basis of the present calculations, roughly one third of the national car fuel consumption would be saved if cold engines did not use extra fuel.

2. Fuel consumption measurements which are solely based on fully warm engines are likely to underestimate national car fuel consumption.

3. Fuel efficiency development programmes which concentrate on the performance of warm engines may miss valuable improvements.

6. ACKNOWLEDGEMENTS

The work was done in the Assessment Division (Division Head: Dr M H L Waters) of the Vehicle and Systems Assessment Department of TRRL.

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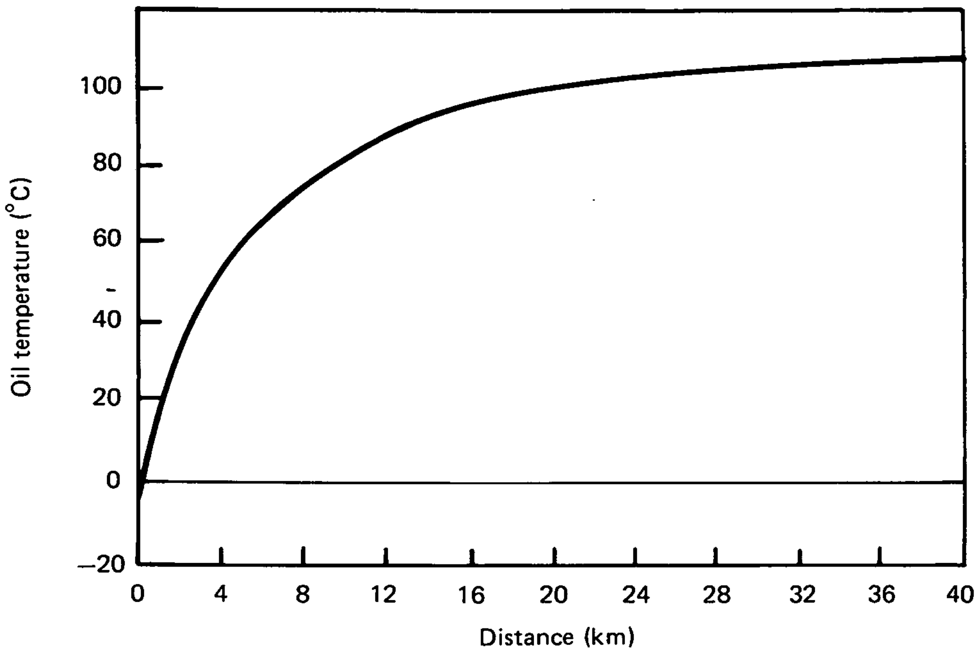

Fig. 1 Variation of oil temperature with distance

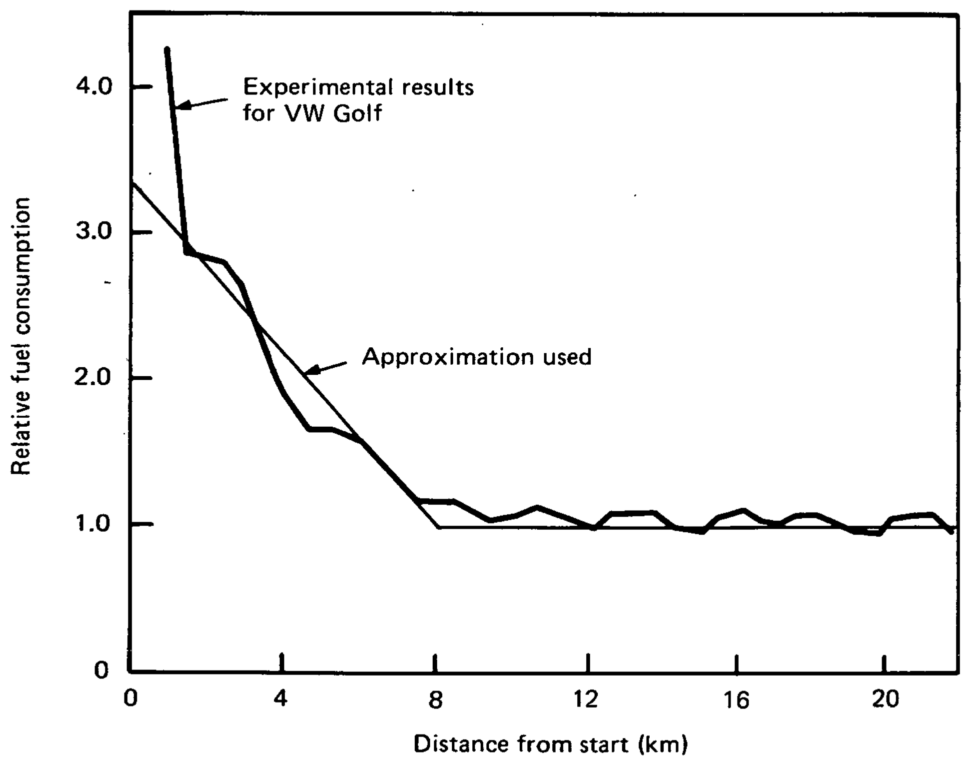

Fig. 2 Fuel consumption by section at 64km/h

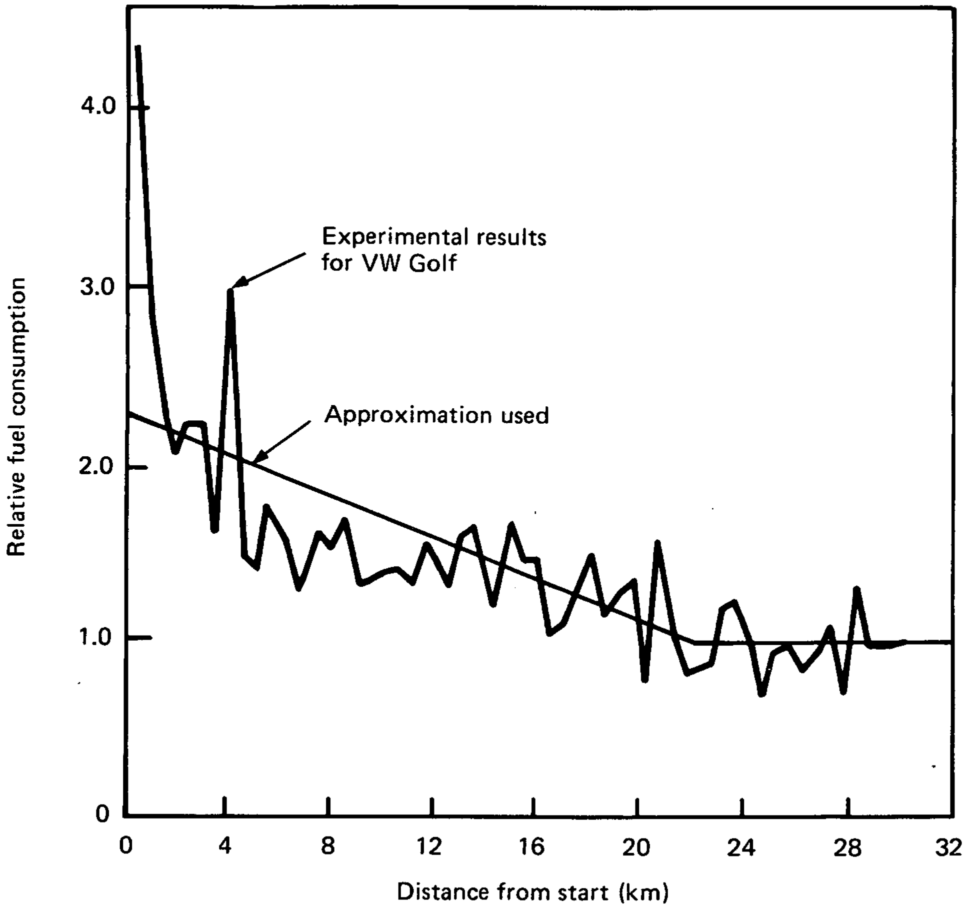

Fig. 3 Fuel consumption by section at 48km/h

(3025) Dd8041326 1,300 12/83 H P Ltd So'ton G3371
PRINTED IN ENGLAND

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