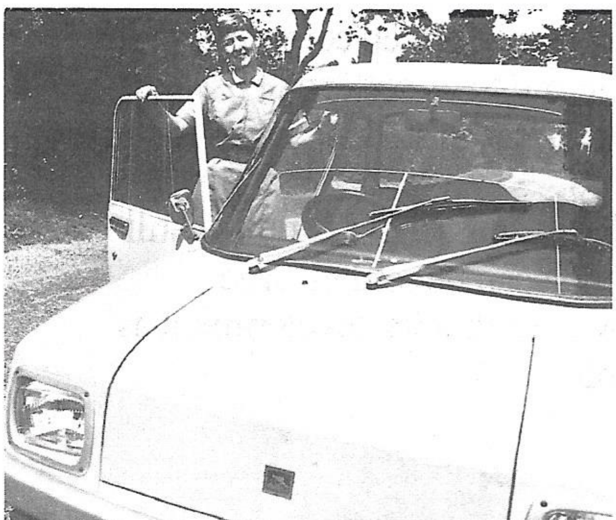
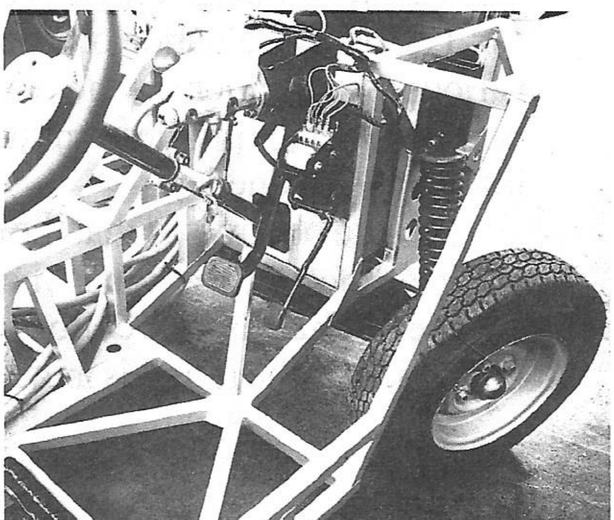
THE ENFIELD ELECTRIC CAR PROJECT





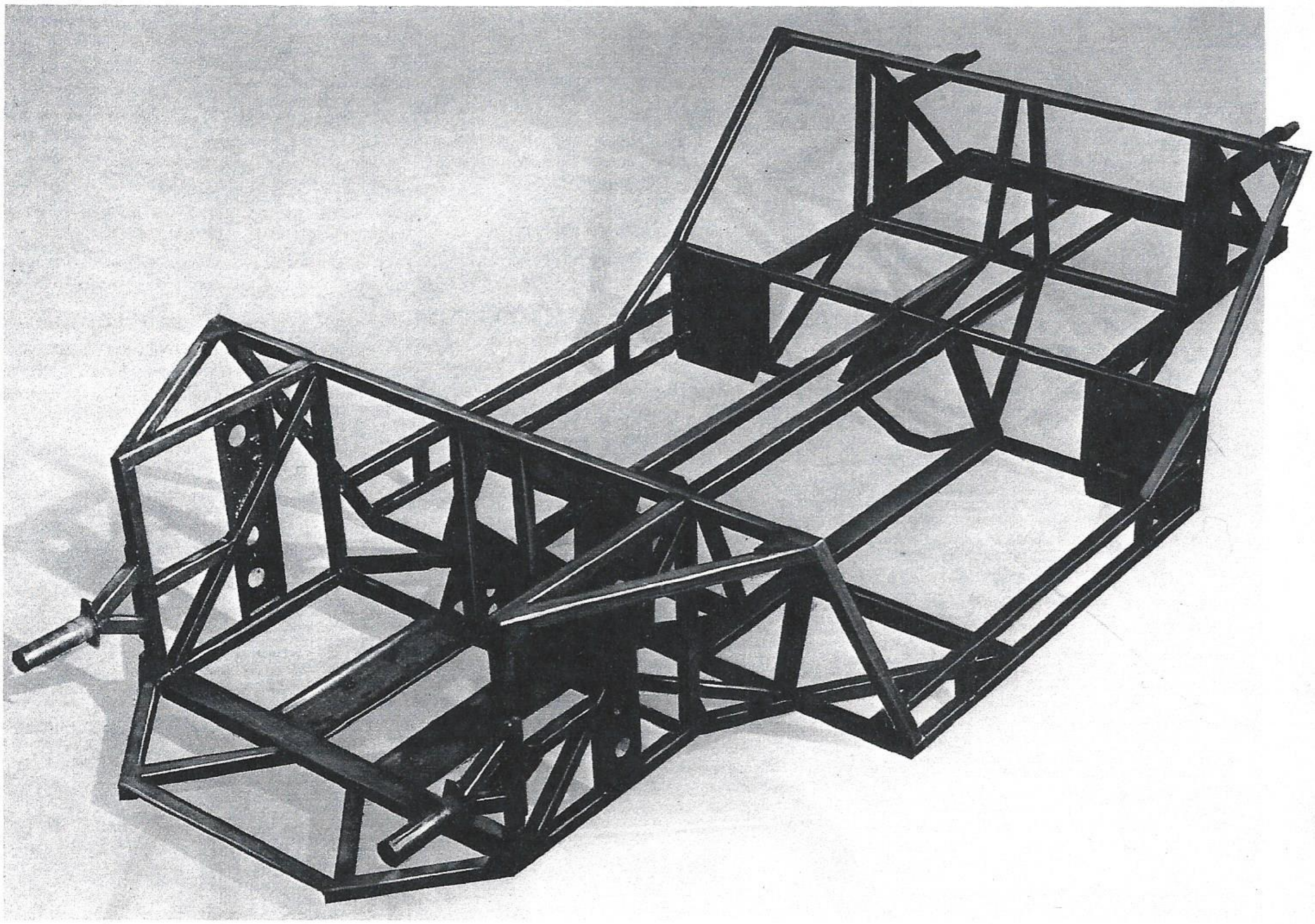
THE ENFIELD 8000 ELECTRIC CAR

In 1966 the Electricity Council decided to evaluate electric car technology and subsequently purchased 66 Enfield 8000 electric cars for long-term tests.

The basic evaluation of the vehicles has been completed and various modifications to the vehicle and to its pattern of use have been made. This publication summarises the valuable information gained.

It has to be stressed that the electric passenger car must still await technological advances before it can be sold in large numbers. There is little doubt, however, that its development as the vehicle of the future is inevitable.

This particular Enfield car has already covered 25,000 miles.



The chassis of the Enfield car.

Vehicle design

The Enfield 8000 car was designed to comply with the United Kingdoms' legislative requirements for road vehicles. The vehicle is designed round a chassis made of square cross section steel tube. Car body panels are of aluminium although other variants use zinc plated steel. The motor is a 4 pole 6kW series-wound machine which is operated at 12V, 24V and 48V. Smooth speed control is ensured by switching the two sections of the motor field winding in parallel and in series at each voltage giving a total of six discrete stages of motor control. Regenerative braking is not used.

The car's traction battery is specially designed for electric vehicle application and is composed of eight 6V monoblocs. Power for the control system and the standard automotive electrics is obtained from a conventional 12V battery.

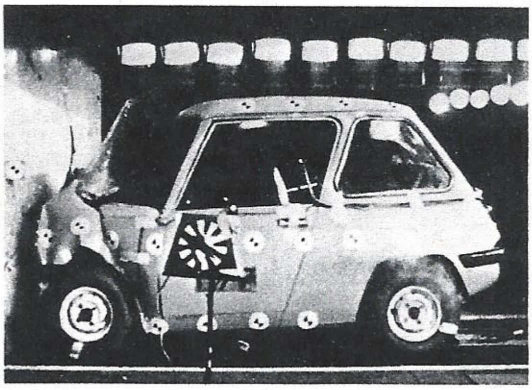
All vehicles are fitted with a charger that recharges both the traction and auxiliary batteries from a 240V, 13A socket outlet. A full recharge can be achieved in about 8 hours.

The maximum speed of the car is 40mph (64km/h) and it accelerates from rest to 30mph (48km/h) in 12.5s. When fully charged the standard traction battery gives the car a range of between 24 and 56 miles (39 and 60km) depending upon driving conditions.

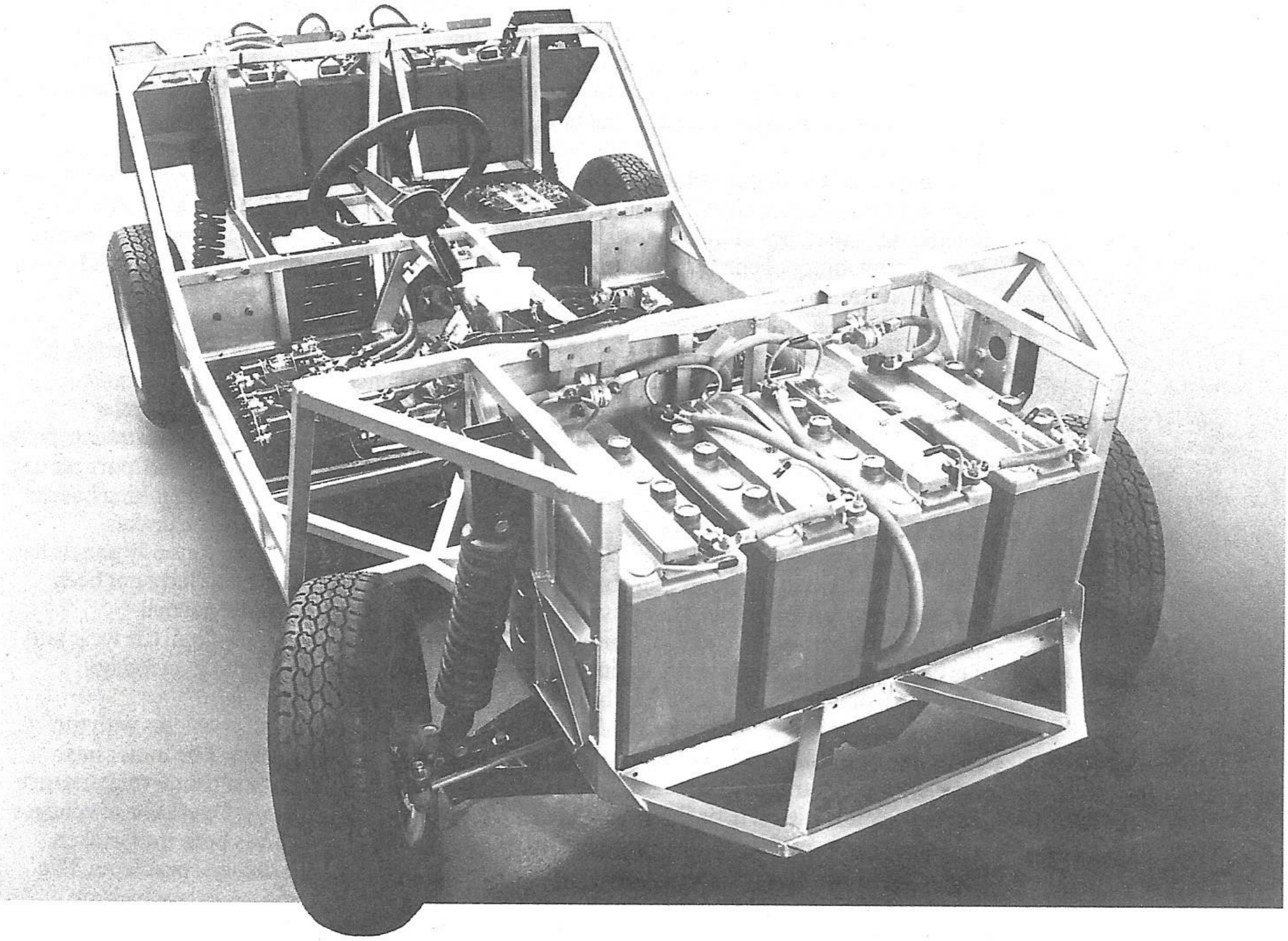
There are now several variations to the basic model which have been developed to test new components and designs. These modifications are discussed later in the report.

The Enfield Report

The first phase of the project (1974-1978) provided valuable information in two general



Britain has the only electric vehicle known to pass standard safety tests. This Enfield car hit a solid concrete block at 30 mph (48 km/h) and passed the crash test with flying colours.

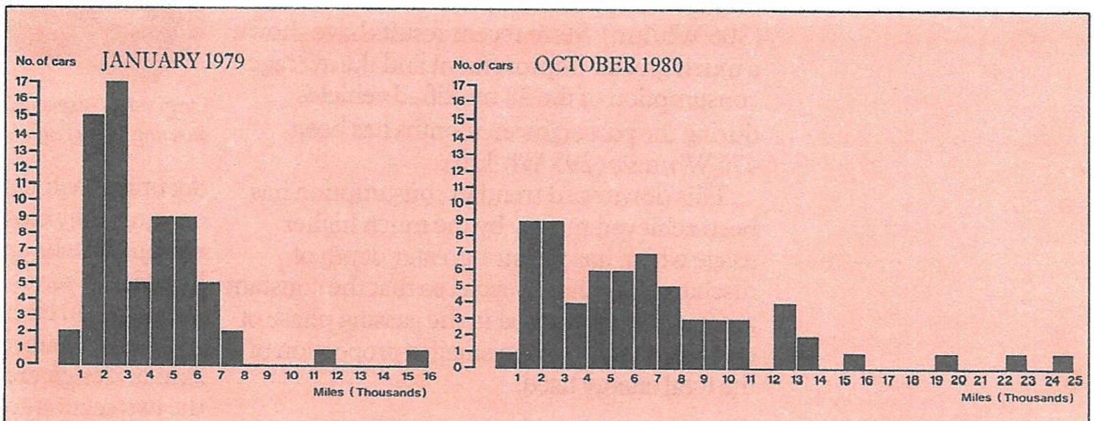


areas: the organisation of a major electric vehicle project and the technical aspects of an electric car requiring further development.

Early organisation of the project required that the fleet was widely distributed, sometimes with only one car stationed at a transport depot. This meant that certain electrical faults could not be rectified quickly by expert diagnosis and repair; consequently many cars received limited use as is apparent from the histogram below left.

Present organisation
Since 1978, in the second phase of the project, vehicles have been concentrated at four main project centres where appropriate expertise has been made available. This policy has not necessarily meant that the vehicles themselves have been concentrated. In fact, London based vehicles have been widely distributed from Basingstoke in the West to Gravesend in the East.

Also as part of the second phase technical weaknesses identified earlier have been



Mileage distribution for Enfield cars participating in the project.

eliminated to ensure high reliability and operational convenience of the cars. This programme of technical modification has proceeded during the past two years and so far 38 vehicles have been completed to the new specification.

The records kept for all vehicles are analysed by the Electricity Council. These include daily readings of mileage, mains energy input, times of charging and parts and labour required for maintenance and repairs.

Vehicle usage

Only 38 vehicles are currently in regular use but fleet mileage has risen from 251 577 miles (404787km) at January 1979 for 66 vehicles to 500 000 miles (800000km) at October 1980.

This is a much more intensive pattern of use than in the first phase, with cars covering annual mileages up to 15 000 miles (24 000km).

As part of the second phase, cars have generally, but not exclusively, been assigned to one driver or family for a period. This driver has been responsible for regular maintenance such as topping-up the battery. Cars have been used for a wide range of duties including commuting in London, Bristol, Newcastle and Ipswich. Other cars have been used for social and domestic duties in urban and rural areas. The cars have been found to be suitable across this wide range of duties and they are particularly liked for their driveability and ease of parking. One criticism from the ladies is that luggage space is inadequate for supermarket shopping.

Energy consumption

The first phase of testing which was achieved with a wide range of batteries, including initially heavy duty starter (SLI) batteries, gave an energy consumption of 500 to 600 Wh/mile (311 to 373 Wh/km).

In an earlier report it was noted that preliminary results for 17 cars fitted with lightweight traction batteries had indicated an average energy consumption of 493 Wh/mile (306 Wh/km). More recent results have shown a much greater improvement and the average consumption of the 38 modified vehicles during the past eighteen months has been 476 Wh/mile (295 Wh/km).

This downward trend in consumption has been achieved mainly by the much higher usage which has meant a greater depth of discharge per charge cycle, so that the constant amount of energy used in the gassing phase of charging has become a smaller proportion of the total energy used.

Maintenance requirements

Maintenance of the cars is routine and simple.

The major regular item of routine maintenance is battery watering. The provision of a single point manifold system has greatly simplified this aspect of battery maintenance. Improvements in battery design and charger reliability have reduced over-gassing and consequently reduced the frequency of battery watering. It is to be hoped that all new batteries will have single point watering systems, and that the need for watering systems will eventually be eliminated.

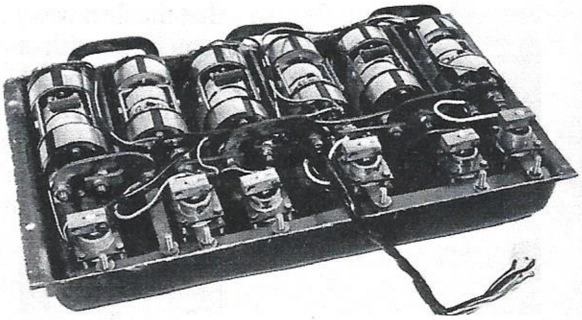
The normal automotive and body components of the vehicle have needed little maintenance. The principal automotive maintenance is confined to an annual examination and necessary adjustments prior to the statutory Ministry of Transport car test. The absence of regenerative braking has not meant undue attention to the brakes.

The use of aluminium for body panels has meant that body overhauls have not been necessary apart from the normal refurbishments resulting from the wear and tear associated with driving on today's crowded roads.

There have been no problems with the motor and transmission. The motor has proved to be reliable and motor maintenance has not been necessary. Operation at voltages higher than normal has been undertaken, again without maintenance problems. The propeller shaft and back axle, which are sometimes subject to failure in electric vehicles, have also been trouble free.

Control system

The Enfield 8000 car, as originally supplied, is controlled by a system of solenoid contactors.

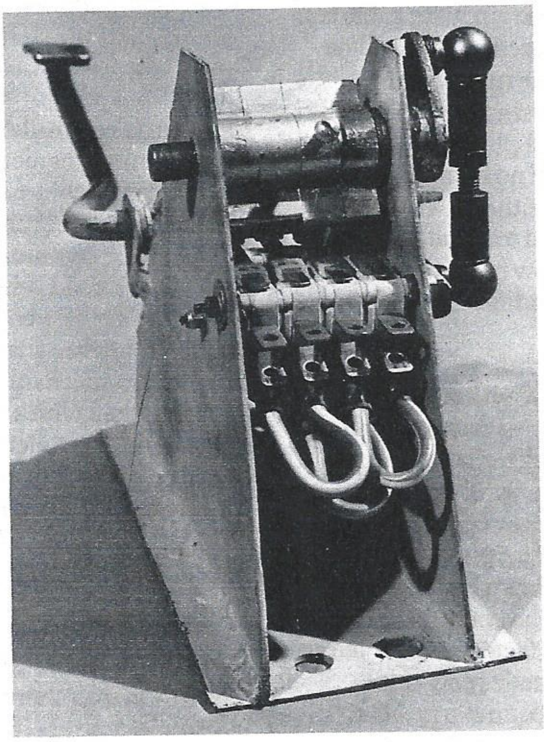


Originally six solenoid contactors were used for voltage selection in the Enfield car.

Six units, each with one normally open and one normally closed contact, are used for voltage switching to give combinations of batteries in series and in parallel. All batteries are always in circuit to ensure a balanced discharge. Four more solenoid contactors of similar design are fitted; two are used to switch the two sections of the split-wound motor field to provide a smooth control of speed, and two are used to provide forward-reverse control.

A single-pole solenoid contactor is used as a master switch.

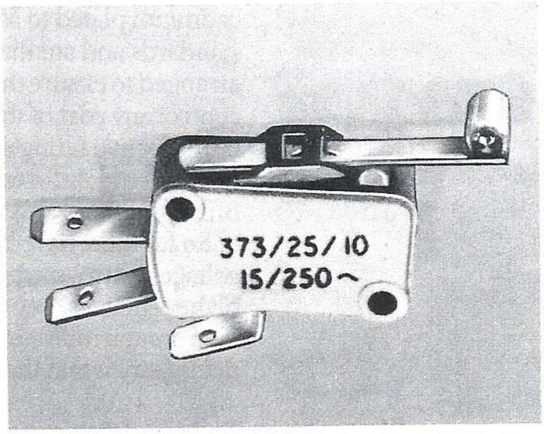
A switch mounted on the dashboard controls the contactor used for forward-reverse selection and a bank of four micro-switches is operated by a cam attached to the accelerator pedal to provide speed control.



Four microswitches are operated by a cam attached to the accelerator pedal to provide speed control.

Microswitches

The microswitch assembly has proved reasonably reliable, but significant differences have been found between the failure rates of microswitches of different manufacture. One make of switch has proved very successful, with no failures yet recorded. This type has a 'C' spring type operation and silver contact faces and is mounted in a glass-filled nylon case.



Microswitch used in the accelerator control.

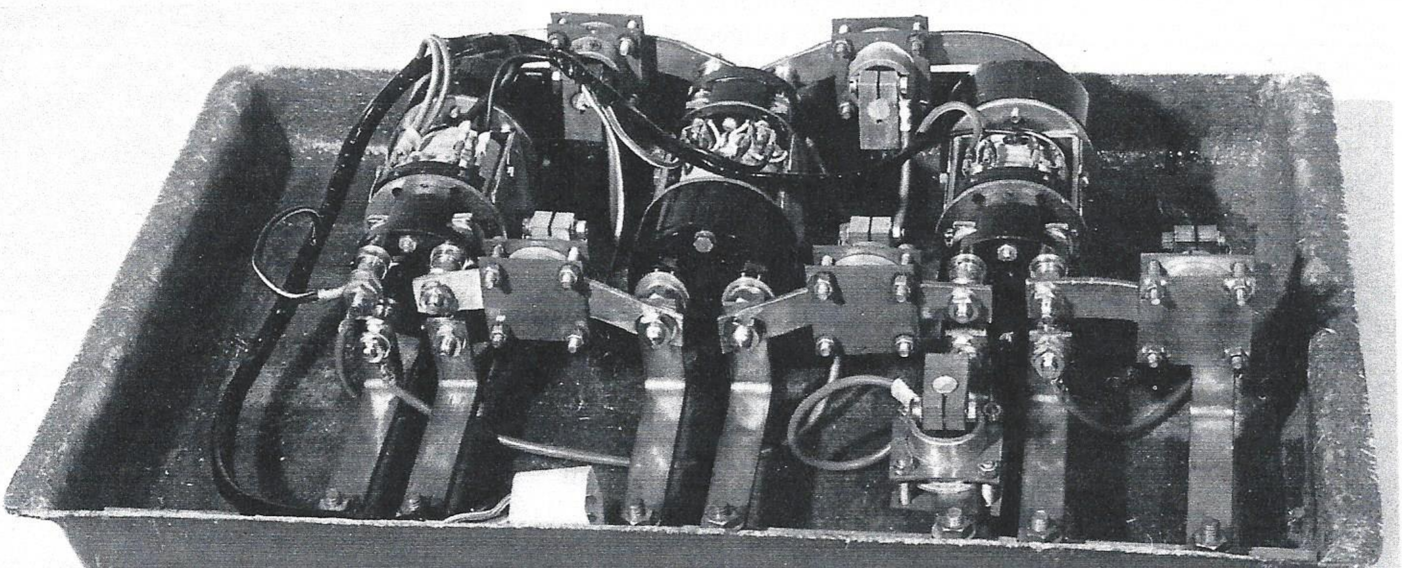
Alternative contactor configuration

The number of solenoid contactor units can be halved by the substitution of units that have normally open double-pole contacts at one end and the usual normally closed single-pole contact at the other. Consequently the solenoid operating current and the number of contact points in the traction current path are reduced.

Initial experience with a voltage controller of this design was so impressive that all cars are now being modified. The system has been assembled to the highest standards with every opportunity being taken to eliminate areas of potential energy loss and failure.

The reduction in the number of solenoid contactors, and therefore the auxiliary current required, has meant that even stronger return

This new solenoid contactor system halves the number of contactors and reduces the solenoid operating current.



springs can be used to improve contact pressure. The cross sectional area of the copper bus bar has been retained but the aspect ratio has been altered to give a wider strip. This gives a higher contact area where bolted connections are made, eliminating possible hot spots. The copper bus bars have been cadmium plated to Ministry of Defence standards and auxiliary cable looms have been arranged to ensure that no auxiliary cable can contact any part of the traction circuit. The retrospective fitting of the new system is entirely straightforward since it is supplied fully assembled and with plug-in looms.

So far there have been no failures of the new voltage control systems either at 48V or the higher voltages now used in some cars. The high annual mileages now being achieved demonstrate that the modifications are sound.

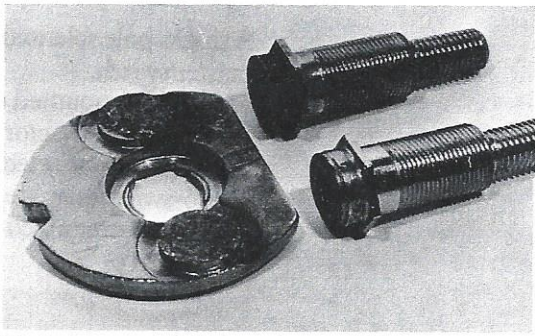
Field and reverse control

Originally the motor field and reverse solenoid contactors were of the same pattern as those used for voltage control. Similar problems were found and in particular there was a tendency for the forward-reverse contactors to stick in the forward, unenergised position. The solution to this problem has been achieved in two ways. The contactor pair has been substituted with a factory assembled pair of contactors with magnetic blow-out. Operation of this pair requires a positive operation of the appropriate solenoid to achieve forward or reverse direction. With this system the master solenoid can be eliminated since this positive action principle provides an isolation in the traction circuit. The contactor used for reverse is now fitted with a heavier solenoid coil and return spring, eliminating the earlier sticking problem.

The other solution has been to eliminate solenoids and effect forward-neutral-reverse selection through a heavy duty three position switch in the traction circuit. This modification has additional safety benefits in that it provides positive isolation of the traction supply.

Contact faces

The selection of the correct contact face material has been found to be of importance for satisfactory contactor operation. Control system failures were encountered in the early stages of the project because of contact wear, resulting in poor contact and contact welding, even though the contacts were protected with arc suppression diodes. The problem was largely attributable to the material used for the contact faces: both pure silver and silver/cadmium oxide contact faces were found to be unsuitable. Silver/tungsten contacts are now used as standard.



Contact wear results in control system failure.

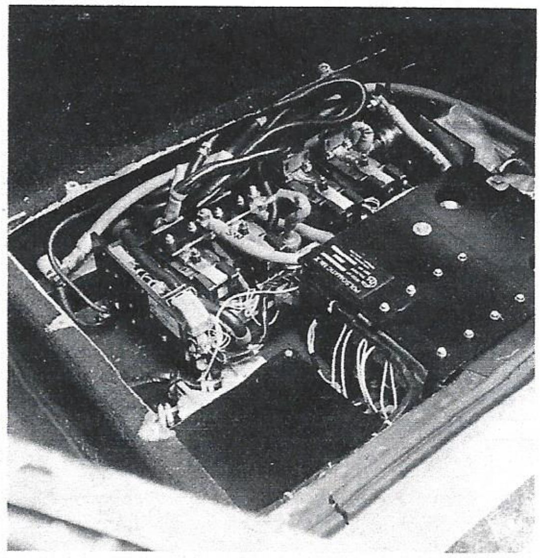
Electronic controllers

The electromechanical control system as modified is proving to be totally reliable; it has the virtues of being cheap and easy to install.

Electronic controllers are now standard on most electric road vehicles and they offer the benefits of stepless control and regenerative braking. They are significantly more costly than electro-mechanical controllers. One car has been fitted with a Cableform Mk X Pulsomatic controller. It has been necessary to fit forced air cooling to prevent the controller locking out on over temperature protection.

Driver reaction to the car has been very mixed. The chopping noise from the controller, aggravated by cooling fan noise has given rise to adverse comment particularly by drivers who are familiar with the standard system. On the other hand driveability is liked; electronic control is infinitely variable and incorporates regenerative braking.

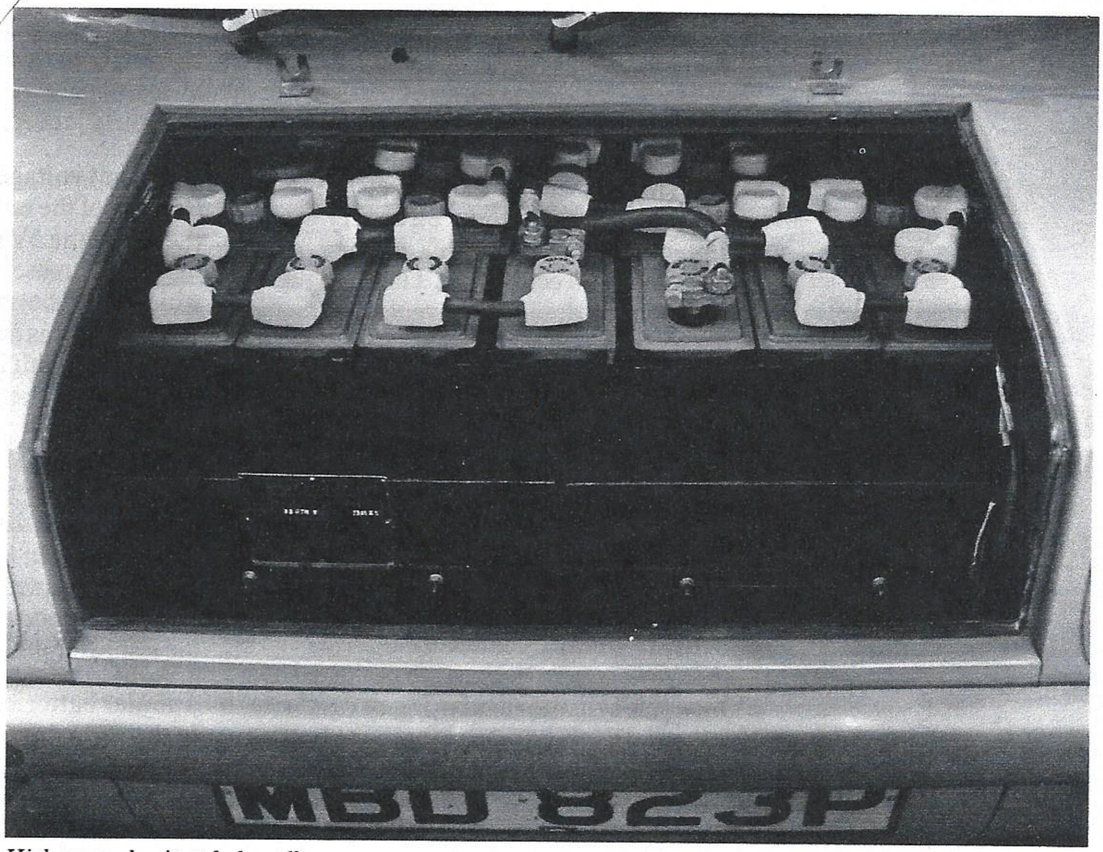
No significant energy benefits have been determined and it is likely that the gains from any regenerated energy are offset by the heat losses in the controller.



The Cableform Mk X Pulsomatic controller.

Safety

The development of any new product requires that adequate attention is given to all aspects of safety. In mechanical terms the vehicles meet all current construction and use regulations.



High energy density tubular cells.

It is now generally accepted that all forms of battery electric road vehicle should be fitted with some form of direct mechanical interruption of the traction circuit which can be operated from the driving position.

The modification of the forward-reverse system using the heavy duty three position switch described earlier meets this requirement admirably. The switch is mounted in a conventional position and even for a driver unfamiliar with an electric car provides for a normal reaction in an emergency situation. The switch also provides for isolation during servicing of the vehicle's mechanical components.

For cars fitted with a solenoid forward-reverse mechanism a simple mechanical switch is fitted in one lead of the motor supply. This switch which is spring loaded is fitted with a two inch diameter knob to allow operation by a simple strike. Both systems have been found to be reliable under simulated conditions although so far neither has been required under real fault conditions.

Correct starting sequence

With the control system wired as in the original design it was always possible to switch-on the ignition while depressing the accelerator, a common practice when starting a conventional car, and cause the car to move.

The control system has been modified along the lines used in cars with automatic transmission and the correct sequence must be used to energise the system. Similarly the system prevents reverse being selected with the master solenoid activated.

Batteries

The battery is the most important component of the vehicle, not least because the running cost of the car is almost entirely governed by the cost of battery depreciation. It is of paramount importance to develop batteries that provide the required range and performance at a competitive cost per mile.

Original configuration

As designed the car used eight 12V monoblocs. Pairs of 12V monoblocs had to be permanently connected in parallel since the vehicle was designed to operate at 48V.

This configuration proved reasonably satisfactory, but as batteries aged difficulties were often caused by unequal current sharing, particularly during the charging cycle. In several cases one monobloc in a pair became overheated. The original batteries supplied were not really suited to traction duties since they were heavy duty starter batteries and not capable of regular deep discharge.

One of the first priorities was to test the new types of battery designed for electric vehicle use.

Battery design

There are two types of the lead-acid battery; the flat plate and the tubular plate battery.

Heavy duty starter batteries are of flat plate design whilst the long life but relatively low power batteries used in industrial trucks are of tubular plate design. For the successful development of high speed traffic compatible vehicles like the Enfield car battery manufacturers must produce a battery with an acceptable combination of life and first cost to give good overall economics. There are two philosophies in designing advanced lead-acid batteries. In the tubular plate battery it is necessary to 'thin down' the plates to increase both energy and power density and retain the high cycle life. The flat plate battery must be "beefed-up" to give the plates longer life. Both designs of these newer types of lead-acid battery are now under evaluation.

Flat plate batteries

Batteries from five manufacturers have been tested. Most battery designs are packaged as 6Vmonoblocs in the standard "golf cart" size. Volumetrically this does not make the best use of the battery compartment space and consequently the range of the car is to some extend compromised.

The 6V monobloc design overcomes the objection when using 12V monoblocs of permanent parallel connection. It is perfectly acceptable to connect batteries in parallel for short periods. It does not however overcome an even more serious objection identified in the evaluation programme.

All too often the test programme has been interrupted by a cell within a monobloc becoming defective. Indeed in the early stages of the programme it was a notable achievement for a set of eight monoblocs to reach the end of its normal life without interim failures of items such as separators. With the improved designs now available this has become less of a problem and single cell failure now occurs less frequently. When failure starts cells go fairly rapidly and it is generally not economic to replace monoblocs piecemeal.

The energy consumption achieved with lightweight flat plate batteries is in the range 400 – 500 Wh/mile with actual value very dependent upon the actual operating and charging regimes used.

Lives for this type of battery are still inadequate for realistic economic performance. At least one manufacturer has recognised this as a limitation and discontinued manufacture. However it should be stressed that other manufacturers believe that life-cost equation can be got right. Typical battery lives for the range of batteries tested in the Enfield car are from 3000 to 10 000 miles.

On the basis of the best performance so far obtained and current electricity costs the ratio of battery depreciation cost per mile to electricity cost per mile is between five and ten to one, depending on whether day or night rate electricity is used.

Different voltage

Because of the range restrictions imposed by the size of the 6V monoblocs, attempts were made to increase the number of monoblocs which could be used. A system using 12 such monoblocs was developed but this required a 72V system with lower voltages of 18V and 36V if the conventional voltage controller was to be used.

This increased voltage did not cause problems either in the controller or more importantly in the motor. The importance of this experiment lay not in the increased range and performance obtained but in the new design freedom which has greatly facilitated the testing of tubular lead-acid batteries.

Tubular batteries

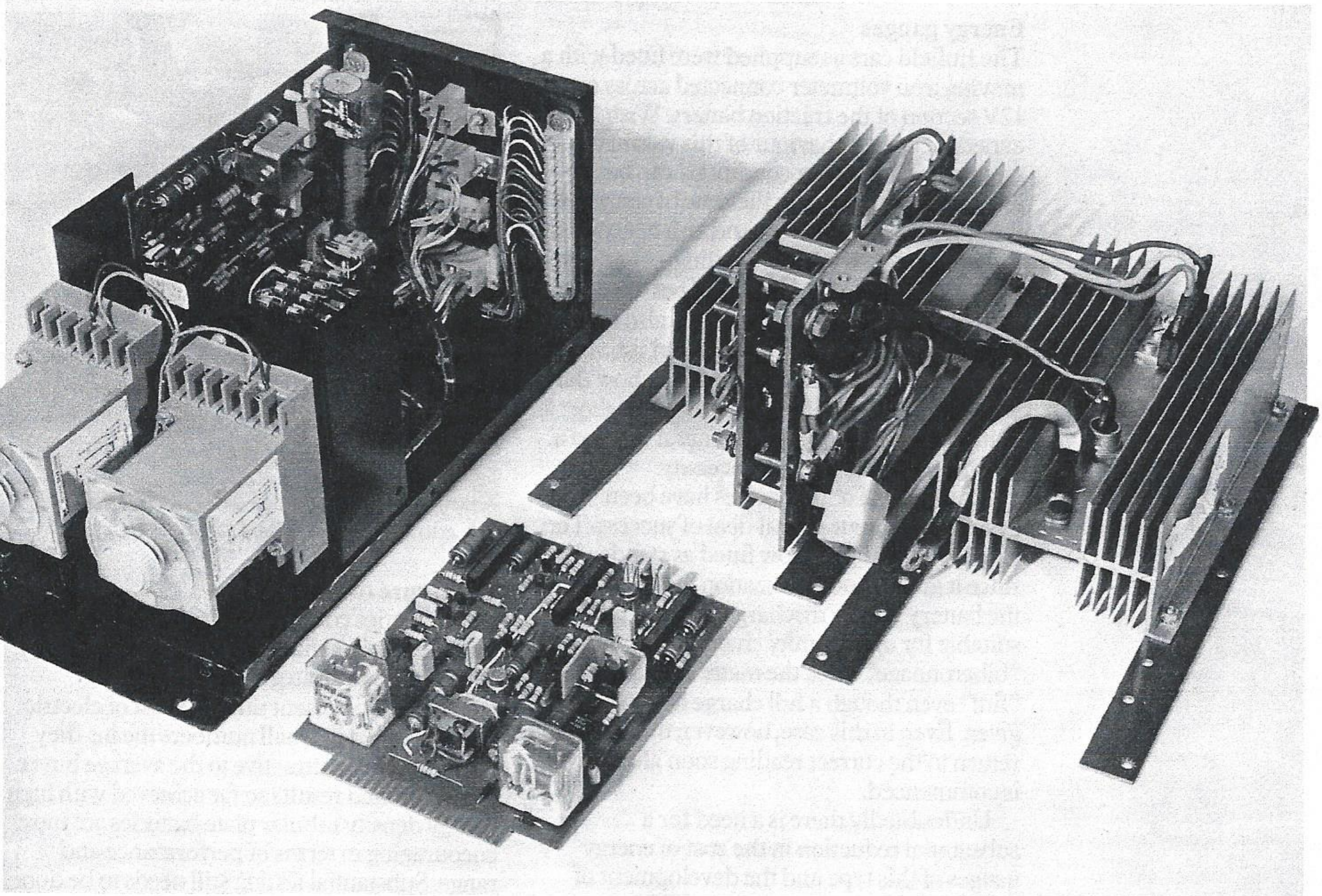
In the early stages of the development of the Enfield, tubular plate batteries were naturally tried because of their well known long life. The poor power density obtainable from tubular plate batteries meant that the performance of the cars was significantly inferior to that when using flat plate batteries.

The success of the experiments on varying the system voltage whilst retaining the 48V motor pointed to a solution for using tubular batteries successfully – increase the battery voltage.

Three cars are now fitted with tubular plate batteries. One car has 56V of Oldham OTM6 standard traction cells which give the car a range of in excess of 60 miles. This car has been intensively used and in just over a year has run 15 000 miles. The energy consumption during this period has averaged 418 Wh/mile. Performance of this car is equivalent to the standard car in spite of the greater mass of battery.

New high energy density tubular plate traction cells, Oldham OTH5, have been in use for a period of three months. The battery voltage is 64V. During this time, which is of course the careful "running-in" phase some 1500 miles have been run at an energy consumption of 348 Wh/mile.The car's performance is excellent. Top speed is in excess of 50 mph and journeys of over 70 miles on a single charge have been achieved. On one test on the public road 41½ miles were run in one hour. During four successive days the car travelled 227 miles and used 75 kWh.

A second car using OTH5 cells has been commissioned and it is hoped to start tests on other high energy density tubular plate batteries shortly.



The rectifiers and controls from the on-board battery charger of an Enfield car.

Chargers

The decision to specify the Enfield car with an on-board battery charger ensured maximum flexibility of use but presented special problems to the designer. Not only is the charger subject to normal vehicle vibration, but space restrictions mean that the charger has to be split into three sections with cable loom interconnections. These three sections comprise the transformer, the rectifier box and the control box. The charger permits an initial taper charge with a starting current of approximately 30A until the battery reaches a voltage corresponding to 2.35V per cell. A lower taper current is then supplied for a variable timed period. The charger independently charges both the 48V traction and 12V auxiliary batteries.

The incidence of charger faults was high at the start of the project. Poor quality control in the manufacture of the 48V mains transformer was a significant factor but good quality transformers are now available and have proved to be reliable.

The remaining charger faults have been associated with the control circuitry, with few failures in the rectifier box. The control circuitry is mounted on printed circuit boards and approximately 40 faults have occurred as a result of failure of both connections and components. Again, the incidence of faults was far higher at the start of the project than at present, indicating that quality control in this area could have been better.

The original charger was manufactured under sub-contract to Enfield Automotive Ltd and only minor modifications have been carried out.

Where non standard battery voltages have been used the main transformer has been rewound to the appropriate voltage and the control system voltage detection levels suitably adjusted. The control and rectifier components of the charger have operated successfully at the higher voltage levels.

There is scope for improvement to the design of vehicle mounted chargers and some limited development work has been undertaken with S & W Charging Equipment Ltd. The charger developed is capable of functioning reliably with up to two failed cells in the normal 48 V battery. The charger has proved reliable over 7500 miles.

The transformer is a bulky component and if on-board chargers are to become popular the weight and size must be reduced. In this context, high frequency chargers may be evaluated during the next phase of the project.

Energy gauges

The Enfield cars as supplied were fitted with a moving iron voltmeter connected across one 12V section of the traction battery. With experience, the behaviour of this voltmeter under various driving conditions can be interpreted as a guide to the state of charge of the battery. On the other hand, to a new driver, this meter can be very misleading, especially if that driver has no understanding of the technical principles involved. It is also useless to a driver taking over a vehicle that is not fully charged since the voltmeter cannot show the amount of energy left in the battery. In short a voltmeter is inadequate for general use and a reliable energy gauge is a necessity.

A number of other devices have been evaluated without a great deal of success. The Curtiss 933 gauge is now fitted as standard since it gives a good indication of the charge in the battery during discharge. It is not very suitable for opportunity charging, "biberonnage", since the meter can reset to "full" even though a full charge has not been given. Even in this case, however, the meter will return to the correct reading soon after driving is commenced.

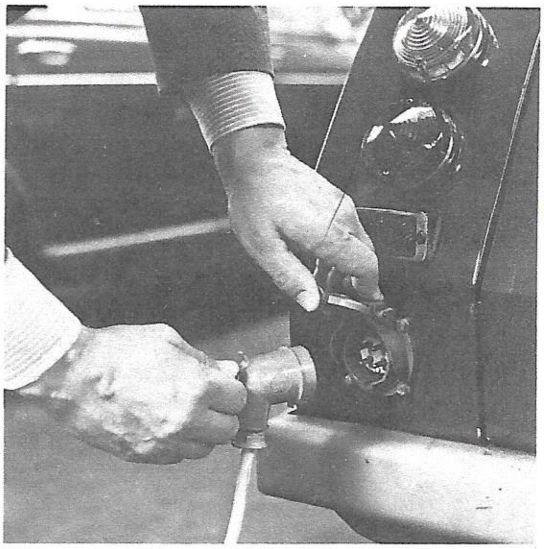
Undoubtedly there is a need for a substantial reduction in the cost of energy gauges of this type and the development of cheap microprocessors could provide a means to achieve this objective.

In the meantime a simple record of the mains energy input and the mileometer reading remains an effective way of knowing the state of charge of the battery.

Minor modifications

In addition to the modifications and test programmes already described, a number of minor modifications have been made to the Enfield car to improve its ease of operation. These include the provision of an externally mounted mains plug to accept the charger lead; previously it was necessary to remove the rear battery cover to connect the charger to the mains supply. The external plug has four conductor pins, one of which is used to complete a circuit preventing the vehicle from being moved whilst the charger lead is connected.

The energy meter that measures the mains energy input to the vehicle has been permanently incorporated as a dashboard instrument.



This external plug and socket facilitate charging.

The future of electric cars

Uncertainties concerning the future of oil supplies require that electric transportation is developed as a strategic transport energy option. At the present time the cost of electric cars produced in small numbers means they are relatively unattractive to the average buyer.

The limited results so far achieved with high energy density tubular plate batteries are most encouraging in terms of performance and range. Substantial testing still needs to be done to show that economic lives can be obtained and that a reliable vehicle range can be maintained throughout the battery life.

Operational experience with cars shows that the compact two-seater whilst attractive particularly to lady drivers has limited market appeal. There may be scope for a light van variant which would be attractive for many commercial organisations with fleets operating in city areas.

Clearly other technical developments will emerge during the next few years and will be kept under review. If appropriate they will be incorporated into the Enfield fleet.

DRIVE ELECTRIC

The Electricity Council – EC3919/10.80