Although my talk to you this evening has been scheduled as "Compression-Ignition Engines," I have taken the liberty of interpreting the heading rather broadly, and propose merely to deal with a number of points which have a direct bearing on that type of engine. I am hoping that some of these points may promote discussion afterwards.

Since I had the pleasure of addressing your Institute last on this subject, much progress has been made both in the use and in the production of these engines, even if that progress, on the face of it, does not appear spectacular. The advance has been somewhat checkered owing to the increase in taxation on C.-I. engine fuels in various parts of the world, and partly to the increase of taxation on C.-I. engined vehicles themselves in other parts, which really amounts to the same thing.

The development has partly been spurred on, and partly slowed down, by the fact that C.-I. engine competition has encouraged petrol engine manufacturers to produce even better and more efficient engines than previously. This is not one of the more serious factors, except in the aviation field.

That progress has been made is borne out by a comparison of the figures for Australia for the years 1936 and 1939:

<table>
<thead>
<tr>
<th>Item</th>
<th>1936</th>
<th>1939</th>
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</thead>
<tbody>
<tr>
<td>Number of Vehicles in Victoria</td>
<td>67</td>
<td>302</td>
</tr>
<tr>
<td>Number of Vehicles in Australia</td>
<td>223</td>
<td>1,368</td>
</tr>
<tr>
<td>Number of Vehicles in U.K.</td>
<td>15,000</td>
<td>30,000</td>
</tr>
<tr>
<td>Number of Vehicles in U.S.A.</td>
<td></td>
<td>5,000</td>
</tr>
<tr>
<td>Number of C.-I. Tractors in Victoria</td>
<td>156</td>
<td>886</td>
</tr>
<tr>
<td>Number of C.-I. Tractors in Australia</td>
<td>1,011</td>
<td>4,593</td>
</tr>
<tr>
<td>Number of C.-I. Engines for Rail Purposes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>in Victoria</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Number of C.-I. Engines for Rail Purposes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>10</td>
<td>87</td>
</tr>
<tr>
<td>Number of Makes of C.-I. Vehicles in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>Number of Makes of C.-I. Vehicles in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Number of Makes of C.-I. Engines for Rail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purposes in Australia</td>
<td>8</td>
<td>13</td>
</tr>
</tbody>
</table>

The largest numerical increase has been in road vehicles and tractors, but this must not overshadow the real develop-
ment which has occurred in the necessarily more conservative branch of traction, namely, railway traction. In spite of the control which exists on heavy transport, this increase in the number of road vehicles operating is due to the more economical performance of the C.-I. engine in general, and in various parts of the world to the use of C.-I. engines in delivery vehicles. Such delivery vehicles are favoured more in country districts than in city areas, as a certain amount of non-stop mileage is possible, which is where the C.-I. engine shows up to its best advantage. This phase of development is still young, but it is one which promises the greatest advance in the future in view of the potential market of such delivery vehicles.

Not only has an advance been made numerically, but also in the method of operation and in the maintenance of these engines, owners and users having learnt much in the last few years which has assisted them to keep their engines in very much better condition.

C.-I. engine manufacturers and distributors, together with the manufacturers of C.-I. engine accessories, have realised the importance of removing from the minds of their customers the thought that the C.-I. engine is something mysterious and difficult. They have, by means of instructional classes and personal contacts, instilled into their customers some knowledge of the way in which these engines operate, and the care which they should receive. The injection equipment manufacturers have possibly done more in this line than any other section.

The knowledge which users have gained, even if that knowledge is comparatively small, is of vast importance, because reputations in the engine and automobile world have been ruined before now through faulty handling and faulty understanding of perfectly sound engines. Fortunately we do not now see, or very rarely see, an owner-driver sitting by the side of some dusty highway filling in the spare time of his luncheon hour by cleaning the engine atomisers with a dirty rag, and then reassembling them in the dust. He has, in many cases through expensive financial experience, learnt that proper care and attention are essential ingredients of good and economical operation.

I think it may be said that the average standard of care and maintenance of engines in this country is as good as that in any part of the world; that does not mean that it might not be better. We still have certain tendencies which must be eradicated.
Progress has also been made in design, and in the materials used in C.-I. engines; also in the more theoretical knowledge of combustion efficiency and lubrication requirements. Such progress is not obvious to the casual observer, but it is definitely obvious when maintenance and running costs are compared with older data, and where weight per horse power is considered.

Similar progress has been made in the high speed C.-I. engine for industrial work, whose design and progress have generally followed that of the vehicle engine. These small high speed engines have generally been cleaned up in appearance and in design, and what is perhaps the most important, have been made as fool-proof and as dust-proof as possible.

The main efforts in the U.K. have been directed towards bridging the gap which exists between that combustion chamber design which gives smokeless and odourless exhaust, and the one which gives minimum fuel consumption. This is one of the most difficult problems of combustion chamber design, and is perhaps one of the most baffling. The difference between the performance of these two designs is not great, but it is sufficient to make large transport concerns interested in the greater economy, and municipal authorities in the cleaner exhausts. It is difficult to forecast what will be the final result, but it will in all probability be a compromise between the air cell and the direct injection type.

C.-I. engines of either transport or industrial design in the United Kingdom and on the Continent run with surprisingly clean exhausts, surprisingly clean compared with many in this country, and more in America. Much of the excess smoke problem here is due to overloading and not to design, there being a tendency to believe that the governor travel stop was placed in position for amusement and not for use, and is therefore removed.

The advent of the two-stroke engine, particularly of the exhaust-valve-in-head type, has allowed an almost perfect shape of combustion chamber to be used. In these the chamber is almost hemispherical, with no restricted air flow, while at the same time it has a hot area of the exhaust valve for extra heat. This, provided the burnt gases are completely driven out, should give excellent results, and allows for moderate supercharge by the scavenge air if this is required.

It would seem that the two-stroke offers much for the future requirements; far more than was ever available in the petrol two-stroke with all its fuel and lubricating problems.
Fuel injection equipment is perhaps one of the most vital concerns of high speed diesel engine practice, and one, in this country, which requires more consideration than is at present being given to it. What I may say in this connection must in no way be taken as a reflection upon the equipment manufacturers, who have done a very fine job of work. They have advanced the injection system from equipment which worked reasonably well to the present equipment which is entirely accurate and most reliable. They have provided pumps which will run for many thousands of miles without attention or adjustment, and injectors, which, provided they are cleaned when necessary, will work satisfactorily for almost as many miles.

The old bugbear of fuel pump wear has been overcome by efficient pump lubrication and efficient fuel filtering systems, and it is comparatively rare now to see eroded pumps, unless after a very considerable mileage indeed.

Good fuel filtering has also reduced nozzle wear considerably, but of course as long as a fluid must pass through a small orifice at high speed and under high pressure, nozzle erosion, to some extent, must always occur. The hardness and the tempering of nozzle metal have also reduced this erosion, and it is rare to see one of the sprayer holes badly distorted or badly torn.

The causes of stuck sprayer spindles, due to the formation of sludge or semi carbon in the finer clearances around the sprayer spindle, have been investigated. Investigations have pointed to the fact that nozzles were becoming overheated, and therefore the cooling of injectors by increased water circulation around them, and by actual fuel cooling, is now common practice; also the use of copper sheaths around the injectors assists in carrying away the heat, while at the same time forming a water seal.

The correct selection, filtering, and refining of the fuels have also assisted in preventing the formation of this sludge in those hot areas.

For many years the oil engine manufacturers were, to a very large extent, under the control of the fuel injection equipment makers, in that the fuel injection people could, or did, only produce certain sizes and certain types of fuel pump and atomiser, thus restricting the type and power of engine which could be produced. This slowed up the advance of the high speed engine to some extent. That condition, however, has passed away entirely, and equipment manufac-
turers now produce such a wide range of pumps and sprayers that any type or size of engine can be produced.

In this country we are producing a considerable number of high speed diesel engines of the stationary type, engines which are of good and clean design, and which are proving themselves as satisfactory in all parts of the Commonwealth. Practically the whole of each engine is manufactured in this country, with the exception of the injection equipment; but so far as I am aware there is no machinery capable of producing pumps and injectors, although the repair shops for the repair and maintenance of these units are available in every State.

It would seem that if we are to produce diesel engines here, and not be dependent upon outside supplies which may be curtailed just when they are most needed, we should attempt to produce pumps and injectors in this country. The production of such units will call for very fine workmanship, and for somewhat expensive machinery. We produce sparking plugs for the spark ignition engine, and I see no real reason why we should not similarly produce the injection equipment for the diesel engine.

In recent years the C.-I. engine industry has concentrated much research work on the production of suitable bearing materials.

With the advent of the C.-I. engine, and with the increase in power per cylinder in a petrol engine, big end troubles have developed to a certain extent, especially where engines are called upon to work at heavy load for considerable periods.

The investigation into suitable bearing material has brought up many arguments about crankshafts and bearing materials, since the tendency to produce harder bearings has inevitably caused crankshaft journals to suffer. However, the manufacturers of both parts have now been working together for a considerable period, with the result that big end bearing troubles have been reduced to a very considerable extent, and crankshaft journal trouble has not been increased from its original low percentage.

Many metals, alloys, and mixtures of metals are used as bearing materials. The term "mixtures of metals" is used to differentiate these from alloys, because whereas Babbit metal is an alloy, lead-bronze bearing metal may be most easily described as a very fine bronze sponge, the pores of which are filled with lead. These two materials can never form an alloy. Each type of bearing has its own advantage
and disadvantage, but generally speaking lead-bronze has become the most popular material for C.-I. engine work. A lead-bronze bearing is one of the most difficult to manufacture, as the secret of good performance—all other things being equal—is the extent to which the mixture in the bearing is homogeneous. The lead-bronze bearing, while able to resist the pressures imposed upon it, cannot withstand the action of compounded oils, under the action of which, unfortunately, it tends to corrode or disintegrate. This creates a problem of some magnitude, since the research work which has been done on cylinder wear, and on ring sticking, has shown that certain materials added to the mineral oil as antidotes for those troubles, act, when in the presence of lead-bronze bearings, in a similar manner to compounded oils, and are therefore detrimental to those bearings.

One disadvantage of the lead-bronze bearing is its hardness. Certain manufacturers who desire to use lead-bronze as a bearing, use a lead-bronze top half and a white metal bottom half, with the object of allowing any hard substances which may find their way into the oil film in the bearing to become embedded in the softer white metal, rather than score the surface of the lead-bronze or the steel, into which they cannot sink.

The search for a suitable bearing material which will stand up to the work involved, and at the same time not be subject to corrosion difficulties with compounded oils, has led to the use of a great variety of metals. In one instance, although not in a C.-I. engine, the manufacturer had used a silver bearing with a thin lead surface, apparently with the object of conveying away heat as easily as possible.

Besides the work which has been done by engine manufacturers, a large amount of fundamental research work has been carried out on the real nature of bearing friction, and the real basic requirements and functions of bearing lubrication. Foolish as it may seem, comparatively little is known about friction or the motion of a journal over a bearing.

Kettering, at the World Automotive Congress in New York recently, talking on research, stated that really we knew very little about some of the most important matters with which we have to deal, and asked any member present if he could explain fundamentally why his hands became hot when he rubbed them together.

Dr. Bowden, in a lecture which he gave before the University of Melbourne recently, showed how when two surfaces were moved over each other the movement was not continuous, but
in a series of jerks—first of all a slide and then a stick. He showed also how, during this process, local high temperatures were developed—temperatures up to 1000° C. The fact that such high temperatures were met with, even when the oil in circulation was quite a normal temperature, shows that much more work is necessary to decide the most suitable metals to use, the finish which they should receive, and the oils which should lubricate them.

Much work has been done on the finish of metals, and it is believed that one of the main factors in the solution of the bearing difficulties which have been experienced is the finish given to both the journal and its bearing.

The correct and efficient lubrication of the C.-I. engine has been very closely studied. The general concensus of opinion is that the less viscous grades of oil are the more satisfactory, having the ability to reach distant surfaces more easily and carry away heat more readily.

Properties other than viscosity are also required, however, and there has been a call for oils with a variety of characteristics—oils with flat viscosity curves, oils which will not sludge, which will not oxidise, which will have high film strength, which will resist heat, oils which will act as good coolants, which will prevent ring sticking, etc. etc.

It is possible, in refining, to produce oils with any of these individual characteristics stressed, but it is not possible by refining to stress each character, and any character can only be emphasised at the expense of some other. This was very obvious in the United States when they became so intensely interested in flat viscosity curves, to the detriment of other lubrication characteristics.

General compromise is the only solution, and this results in really good oils, but oil cannot be expected to do the work which the engine designer should have arranged to be done by other media.

With the occurrence of higher piston speeds, higher r.p.m., and greater power developed per cylinder has arisen a certain amount of trouble in the nature of ring sticking and varnish. The higher power output necessitates a greater transfer of heat from the piston to the cylinder walls, while the higher piston speeds and higher r.p.m. leave less time for this transfer to occur. The result is higher piston and piston ring temperatures unless special steps are taken to extract the heat from the piston in other ways.
The oil cooling of pistons by means of controlled and circulated flow is virtually impossible in the light-weight vehicle engines, and therefore other means must be adopted. Transferring the heat along the connecting rod means sensibly higher big and small end temperatures—a not altogether satisfactory solution, while cooling the crown of the piston by an oil spray tends to create carbon, and cooling the cylinder walls to a lower temperature to encourage heat transfer tends to some extent to interfere with the best engine performance; the final solution probably lies in a compromise of these methods.

In the meantime, piston temperatures are high, and the effect of this extra heat transfer from the piston to the cylinder walls is that the oil between must also transmit the heat, and, in the process, become exceedingly hot. The result of submitting the oil to these extreme temperatures is, amongst other things, in some cases a varnish formation on the cylinder walls and piston skirt, which is rapidly followed by stuck piston rings, with all the attendant consequences.

Varnish, when it does occur, seems to prefer to develop in areas of fine clearance. It has the appearance of ordinary commercial shellac when dried, and varies in colour from a light oak to almost black. It is rarely found in any depth, and mainly is of about one-thousandth of an inch in thickness. It adheres to the metal in the most astonishing manner, and is extremely difficult to remove, except by the use of special solvents. This varnish rarely appears on parts of the engine where two surfaces are not in contact. Valve stems and guides are also favourite haunts of varnish.

What varnish is, and the actual reason for its formation, are still mysteries. It has no fixed rules for appearing, and may appear or disappear for no apparent reason. It is more evident in new engines than in old, but is just as likely to appear suddenly in an old engine when most unexpected.

The only means of preventing the possible formation of oil varnish is to prevent the oil between two adjacent and moving surfaces from reaching the temperature of above about 275° F., which is an almost impossibly low figure. Frequent oil changes and good flushing will also reduce the tendency to oil varnish. At the present stage it is impossible to state what type of oil will tend to give varnish formation, and what types will not. Here again there is no consistency.

Since engine manufacturers have been unable to avoid the higher temperatures between piston and liner, and between the valve stem and its guide, efforts have been made to find
dopes which will tend to prevent the varnish itself from adhering to the metal. These dopes act generally as an anti-flux, and do not actually prevent the formation of varnish.

There are certain oils available to which such dopes have been added, but they are, in general, made for particular purposes or particular engines, and while in most cases they do prevent the formation of a varnish skin, and of ring sticking, yet they have a tendency to increase wear and to increase other undesirable characteristics found in used oil, when not used according to directions.

The work which is being carried on to investigate the problem of oil varnish will, without doubt, produce a solution, either by methods of refining, or by the use of additives.

The view is held in some quarters in America that, in future, most of the lubricating oils will be doped to prevent ring sticking and to reduce wear, but this view is not held universally. In any case, very much more research work has to be carried out on such dopes before they are accepted universally. For one thing, the dopes which are required to alleviate these two conditions are diametrically opposed, the one acting against the other. Also, no good purpose can be served by minimising one trouble only to find another problem, possibly eventually of a more serious nature, has been produced.

There is still considerable discussion as to the most satisfactory fuel for the high speed C.-I. engine. Admittedly this discussion has now reached its finer points, and is more of an academic than a practical nature.

The angles of the discussion usually are determined by the most suitable fuel for a particular type of engine with a particular type of combustion head. Opinion on fuel requirements of engines will probably continue to vary as long as there is so much diversity in head design.

Previously, there was considerable discussion on the type of fuel required for the petrol engine, but since petrol combustion space design has more or less settled down, the fuel requirement has now settled down, mainly to one of anti-knock requirement, due to compression ratio. Obviously, if the C.-I. engine is to be universally accepted, and therefore to be a complete success, it must be capable of burning a universally available fuel of a standard commercial type. By this is meant a distillate fuel which is available, and not the heavier residual fuels which are available for slow speed diesel engines or burning purposes.
There is more general agreement on fuel requirements in the United Kingdom and on the Continent than in the United States; this is probably due to the greater advance made in those countries compared with the United States. In the last-named country there is a tendency to design engines to run on fuels such as No. 1 Stove Oil, which is a fuel intermediate between a power kerosene and the distillate fuel which is sold on this market for high speed diesel engines. In the remainder of the world the universally available distillate fuel is considered the standard type.

It may be remembered that very considerable discussion has taken place on the ignition quality required by compression-ignition engines. Research work at present being conducted tends to show that while ignition qualities are of the utmost importance, ignition quality, spontaneous ignition temperature, or Diesel Index may be too high, and that the average or lower quality fuels may actually give a better power output performance than when an exceedingly high quality fuel is used. The explanation for this is not available, but it is fortunate that such is the case, because it means that fuel producers will not be required to search amongst their crudes for limited quantities of special distillates, but can use the more generally available, and so cheaper, distillates, which are similar in all characteristics—except ignition quality—to those rarer products which it was previously thought would be necessary as the C.-I. engine developed.

The quality of fuel which is available in Australia is generally the standard quality available throughout the rest of the world, and as such may be said to be eminently satisfactory for its purpose.

It may be said that no fuel problems exist where the correct type of fuel, namely, a distillate fuel, is used, but a very definite problem does exist where other and more viscous fuels are placed in these engines. Quite apart from accelerating the wear in both the fuel pump equipment and in the cylinder liners, due to impurities of the fuel in one case, and poor combustion in the other, the whole question of filtration must be considered.

The filters provided on high speed engines are exceedingly fine, and are liable to choke up when fuels other than the correct ones are used.

In some recent tests which were carried out on two good filters well known on this market, a correct type distillate fuel obtained from an ordinary consumer failed to block the
filters after 100 gallons had flowed through, while when a more viscous type of fuel—such as is normally sold for slower speed engines in this country—was used, the filters became blocked after only 10 gallons had been circulated. It is obvious from this that the filters were doing their work, but it also proves that the selection of the correct grade of fuel is as essential if fuel is to reach the injection equipment, and so the combustion space.

While the filters on most C.-I. engines are almost perfect, there yet remain a few refinements to be made. One of these refinements is that the filter unit itself should be heated, possibly by the circulating water. In this way separation of unwanted particles from the fuel would be facilitated, because the fuel itself would be less viscous, due to its higher temperature. This would be particularly apparent during the colder portion of the year.

The problem of indicating the high speed diesel engine has not yet been solved, although, with the introduction of the Cathode Ray indicator, some solution is in sight.

For engines with speeds of over 300 r.p.m. the Drum and Pencil type indicator cannot be used, owing to the inertia of the moving parts giving false readings. For such engines, until quite recently, the only portable instrument available was the maximum pressure indicator, which was used extensively. This instrument was useful, but it indicated only maximum pressure, and did not assist by giving any other indication of engine performance, such as can be obtained on slower speed engines, with full diagrams.

The R.A.E. electrical indicator is used by many manufacturing firms to give actual pressure diagrams, but again, this is not a portable unit, needing special equipment and special fittings to obtain results. It is, however, an extremely useful instrument on the test bed, or in large installations, for taking averaged diagrams.

The Cathode Ray indicator is being used in progressively greater numbers, as it is the only indicator so far available which will give single cycle diagrams in high speed engines. It is useful, also, in that it can be so arranged to indicate the commencement of injection by the fuel pump, the pressure in the fuel pump during its operation, the rate of pressure rise in the combustion space, as well as the actual pressure rise. The equipment gives a visual diagram on a ground glass screen, which can, of course, be photographed if records are required.
The disadvantage of the equipment, at the moment, is that it is not an easily portable unit, owing to the heavy batteries which are necessary, and also that it is a somewhat delicate instrument to transport, particularly the Cathode Ray element itself. The instrument, however, is used in practically all engine manufacturers' works and research beds, but has so far found little use as a service unit, except in larger installations, where it is permanently fitted. It is hoped that shortly a lighter, more sturdy, and more portable unit of this type will be available. Such a unit would be of considerable assistance to engineers who are concerned with checking engines and finding troubles.

I had hoped to be able to give figures on the comparative cylinder wear which occurs in this country and in the United Kingdom, but unfortunately my information is incomplete, and therefore not reliable.

It would appear, however, that, generally speaking, the cylinder wear in this country is lower than in the United Kingdom. The reasons for this are not entirely clear, unless it be that the average operating temperatures are higher here, due to the higher average air temperatures.

Incidentally, it is extremely difficult to obtain reliable figures on wear or maintenance costs, as so few concerns keep anything like reliable data on which to base any calculations. It is rather a pity that such records are not kept, as they could supply very much information of value, not only as to the cost of operation, but as to the efficiency of equipment.

Of the new units which have been recently developed, possibly the General Motors' two-stroke engine and the Waukesha multi-purpose engine are of the greatest interest. The General Motors' engine is a two-stroke which has been designed to be as light and compact as possible, and to run with the minimum of vibration. Excessive vibration is overcome by balancing the out-of-balance forces by eccentrically-weighted camshafts and layshafts. The air is supplied to the cylinder under a pressure of about 4 lb. through inlet ports at the bottom of the cylinder, the exhaust taking place through a valve in the cylinder head. The injection pump and sprayers are of one unit design, situated on the cylinder head. They can be removed completely without disturbing any other engine setting.

It is improbable that we shall see this engine on the Australian market for some little time, but it is being used quite extensively in America at the present time.
The Waukesha multi-purpose engine is an effort to reduce the cost of engine construction, and may very well play an important part in the future in the reduction of costs of manufacture. The engine has been designed of suitable strength for a diesel engine, and sufficiently light to be capable of use as a petrol engine. The only alterations which are necessary to convert from one type to the other are a change of pistons, in some cases a change of head, and the replacement of magneto and plugs by fuel pump and sprayer nozzles.

The engine can be used as a motor spirit, kerosene, or Hesselman engine merely by the alteration of pistons and injection equipment.

How far this unit will affect the general production of engines in America remains to be seen, but it may be said that the automotive industries in that country are very interested in it.

In spite of the fact that Great Britain supplies the majority of diesel-engined road vehicles in this country, it supplies virtually no diesel tractors. The tractor market here is supplied by three main areas—Australia, U.S.A., and Germany. Obviously, the reason for this is that the United Kingdom supplies only a small percentage of the tractors used on this market.

The Australian-produced diesel tractor is one of medium speed and single cylinder type. The German tractors are of both medium speed and high speed, while those diesel tractors supplied by the United States are all of the high speed, multi-cylinder, vertical type (and it is with this type that we are mainly concerned).

The general construction of the units is similar to the automotive unit, but, of necessity, is of sturdier design and generally heavier in weight. It also probably operates at a slightly lower r.p.m.

In spite of the low cost of fuels in the United States, where the difference is small between gasoline, on which most farmers operate their tractors, and gas oil, the fuel for diesel tractors, the slight fuel cost saving, together with the better efficiency, has made the diesel attractive to the American farmer, who is perhaps the most conservative of all machinery users.

The majority of tractor manufacturers in the United States are now either building, or seriously consider producing, diesel tractors of some type. It may almost be said of the
United States that the diesel tractor has tended to force the diesel road vehicle into production, whereas in other countries the reverse is the case.

There can be no doubt that the Diesel Train, as it is known in the United States, has been a distinct success—a success not only from the railways point of view, but also from the passengers' point of view. The general public has accepted the diesel train and fully approves of it. This acceptance by the public is due to one or two main reasons:

Firstly, the cleanliness and comfort of the trains, which are all completely new. They have been specially designed for comfort, and are air-conditioned; moreover, as operated by a diesel engine, they do not suffer from the smoke nuisance of trains hauled by steam locomotives.

Secondly, the faster schedules of the diesel trains have encouraged the public to travel. These faster schedules are due to the lighter construction of the train, and to the quicker acceleration, which is possibly due to the diesel engine itself, and to the lightness of the train. The actual maximum speeds are in many cases not very much in excess of modern trains drawn by steam locomotives, but the possibility of higher speeds around curves, and the better acceleration after slowing down for a curve, all tend to give higher average speeds.

Thirdly, publicity has caused these trains to become fashionable as well as popular. They are so popular indeed that I was unable recently to get a seat on the "City of San Francisco" Express running between Chicago and San Francisco, being the 168th on the waiting list some fourteen days before I wished to travel.

The locomotives of these trains are well maintained and are under constant close supervision, with the result that their time off the roads is extremely small. On many of the 500-1000 mile runs, which can be completed in the day, one line of cylinders is taken out for inspection, cleaning, or replacement at the end of each day, or each alternate day. This virtually means that the complete engine is inspected and receives a top overhaul every 6000-10,000 miles.

The fuel, which is of the standard distillate type, is carefully filtered before being filled into the locomotive's tanks, and the engine oil is changed regularly every 6000 miles.

The type of engine used is the Electro-Motive Company's V type, two-stroke, of six, eight, or twelve cylinders, depending upon the power required. These engines used a
compression pressure of 600 lb. to the square inch, and develop 75 h.p. per cylinder for passenger work, and 100 h.p. per cylinder when used in shunting locomotives.

The injection equipment is a pump and injector in one, a separate unit naturally being used for each cylinder. Fuel is injected at 800 lb. per square inch pressure through a 5-hole sprayer.

The pistons are ingeniously oil-spray cooled.

The largest locomotive so far produced is a power car containing two 12-cylinder engines for driving purposes, as well as an auxiliary engine for lighting and air-conditioning purposes. The engines and locomotives are both as light as possible, being completely built by welded construction.

It is improbable that very many more diesel trains will make their appearance in America until some of the older rolling stock has been used up, even though they have become so popular.

The position in the United Kingdom shows that not nearly so much advance has been made, and there are no diesel trains, as such, operating there. A considerable number of rail cars are in operation, and numerous shunting locomotives are used. These all appear to be giving satisfactory results, but there is little tendency to increased numbers, owing, in all probability, to the availability of cheap coal.

The advance made in Australia has not been spectacular, and yet it has been very real. The diesel trains operating in New South Wales have proved themselves, and are accepted as a success, while diesel rail cars are in operation in every State. Owing to the high initial cost of placing completely new trains in service, the advance in rail work must be slower than in road work.

The only branch of the C.-I. engine industry where very little progress has been made is in C.-I. aero engines. In this field Germany has perhaps done more work than any other country to produce, test, and use C.-I. engines. Other countries have carried on a considerable amount of research work, but have not gone into production. British engineers have considered the question closely, but the availability of 87 and 100 octane number aviation gasolene—enabling petrol engines to develop almost the same efficiency as a C.-I. engine, even if in a more expensive manner—has largely prevented C.I. engines from being produced commercially.

It is admitted that the use of such high anti-knock fuels is expensive, but since the majority of engines are used for
military purposes, where high efficiency and light weight are the main factors, the extra expense is not of any very serious consequence. Nevertheless, the British Air Ministry have been doing a considerable amount of work on such engines, particularly on the supercharged types. Had progress not been made in the development of high anti-knock fuels, there is no doubt whatever that the C.-I. engine would have been used, commercially at least, almost universally by this time.

As to the future, it appears to me that where motoring is done for pleasure the petrol engine will remain supreme, but where it is carried on for commercial purposes, and where low costs are essential, the C.-I. engine will be in the majority. Tractors, I feel, will change over steadily to the diesel type, but aero engineers will continue to use high performance petrol engines, even if of the petrol-injection type, for many years to come. As for C.-I. engines themselves, through force of habit the four-stroke engine will remain popular, but will be slowly overtaken by the lightly supercharged two-stroke engine.
A general discussion took place at the close of the lecture, Messrs. Gamble, Watson, Peakman, Pyke, Cumming, and others taking part.

In reply to queries, the lecturer said that very little was known about this new kind of varnish peculiar to the C.-I. engine, but it was definitely due to lubricating oil, a low grade forming it quicker than a high grade. It seems to be formed only when exceedingly fine clearances occur. The trouble is really very rare, but when it does occur, things become desperate as the pistons seize solid in the cylinders. The great publicity now taking place is for the purpose of gathering data from which a starting point may be made for the solution of the problem. The varnish formed by fuel is of a different nature, being softer and more sticky.

With regard to bearing metals for big ends with very heavy loading, the Junkers people have been for a long time using a silicon aluminium alloy. Silver is used in some cases with good results, but silver cadmium alloys are chemically affected by compounded oils. Research is proceeding with reference to burnished as compared with finely-ground finishes, and some interesting results have been obtained.

The C.-I. engine has less breakdown trouble, uses safer fuel, and is more economical than a petrol engine. Thus it has many sterling qualities for aero work. A lengthy regular service of 10 planes per day between Germany and England has proved its reliability. There would be difficulties in the way of manufacturing injection sprays and pumps in Australia. Special costly machinery and highly-skilled workmen are required, whilst a limited sale would not make for economy in manufacture. As an instance of some of the difficulties involved, the lecturer mentioned that in some multi-jet units the bore of the holes is only 0.0015 inches, and that the exact direction is generally very critical.
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Street, Ralph

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