# Cold-Starting Aids for
# AUTOMOTIVE DIESEL ENGINES

BY CARLTON H. PAUL

COLD starting is by no means the least of the problems encountered in designing a high-speed Diesel automotive engine. The ability to start is naturally a prerequisite for an engine whose performance is to be considered satisfactory, and this starting must be accomplished consistently in all types of weather. During the past few years, the laboratories of the various engine manufacturers have found numerous methods of aiding cold starts, but the problem is still of major importance to both the manufacturers and the armed forces. The purpose of this paper is to present some of the most successful of these cold-starting aids.

Primarily the characteristics of the engine must be such that ignition temperatures for the fuel will be reached in the combustion chamber when the engine is cranked at its minimum starting speed. All of the aids to starting, then, will endeavor to raise the air temperatures to these auto-ignition temperatures. This may be accomplished by:

(a). Cranking the engine faster so that the comparative heat loss in the combustion chamber will be less;

(b). Using fuel oil or doped fuels with a low auto-ignition temperature; or

(c). Applying heat.

In connection with the first item, it will be of interest to note that combustion systems of the quiescent type are inherently easier to start than the turbulent type, due to the fact that there is less heat loss through the cylinder walls. Thus a direct injection engine will start more readily than one with a turbulence chamber.

Assuming, then, that any one or all three of these aids must be used in cold weather, let us examine some of the most promising possibilities of each. In such cases, it will, of course, be necessary to hold two of the three variables constant while examining the third.

## CRANKING SPEED

With the type of fuel and the injected fuel quantity held constant, and with no heat applied from an external source, the engine will have a minimum or critical cranking speed at a given ambient air temperature, below which it will not start. This is because the heat of compression minus the heat lost in the cylinder does not reach the auto-ignition temperature of the fuel. Now as the engine is cranked at some speed greater than the critical, the ignition temperature will be attained and firing occurs. Thus the problem arises of how to increase the cranking speed. A curve of cranking torque versus cranking time at a constant temperature is shown in Fig. No. 1, and one of cranking torque required to motor the engine at a constant speed at various temperatures is shown in Fig. No. 2. It will be noticed that the torque requirements are at a maximum at break-away when the oil films are being sheared and that the torque is an inverse function of the temperature. These demands of a particular engine must be estimated and consequently a cranking motor of suitable output selected.

The electric motor has become the most widely accepted cranking mechanism for the automotive Diesel, primarily because of its small size, light weight, and high torque output. It does have the disadvantage of being unable to produce sustained cranking for more than a few minutes because of discharging the batteries. Cartridge starters have also been used, but have not found favor because of the short cranking period per cartridge and because they apply high instantaneous loads on the engine parts. Small gasoline engines also are used on some Diesels. They are relatively heavy and bulky, but do have the advantage, and an extremely important one at subzero temperature, of being able to crank the Diesel for a long period of time. The above-mentioned cranking torque is directly a function of the viscosity of the lubricating oil and it must be assumed that the correct grade of oil will be used at the low temperatures. The cranking torque may be reduced considerably by diluting the lubricating oil with kerosene or a similar agent, but such a solution is not satisfactory when the engine becomes warm unless the dilutant is volatile. It is interesting to note in this connection that some aircraft gasoline engines use this dilution method in cold weather. A certain percentage of gasoline is used to dilute the oil before the engine is shut off and the next time it is started the highly volatile gasoline is vaporized off the lubricating oil as it becomes warm, leaving the oil in its original state of viscosity.

At subzero temperatures, however, it will be found impractical to select a starting motor of sufficient capacity to assure starting without other aids, because of the size and weight of the motor and auxiliary equipment, such as batteries. Consequently, other starting aids must be found.

## FUEL OIL

The proper selection of fuel oil or the use of doped fuels will materially aid the starting. First of all, the fuel oil must be able to flow freely at the starting temperature. It is fortunate in this respect that the viscosity of most fuels varies inversely with the cetane number, which has been found to be the most significant variable as far as starting is concerned. The cetane number is a measure of the ignition quality of the fuel. A curve, showing the cetane number plotted against the ambient temperature, is given in Fig. No. 3. It will be noticed that the effect of the cetane number covers a relatively short temperature range.

In laboratory tests, fuel dopes have been added to the intake air and some have been quite successful as an aid to starting. The most promising include amyl nitrate, chloropicrin, ethyl disulfide, and ethyl ether. From starts obtained with these additives it was found that they essentially increase the cetane number of a given fuel by as much as 60 to 70 cetane numbers. The additives are not mixed with the fuel actually to produce a high cetane number, but rather are put in the inlet manifold. The starts thus obtained could be used to extrapolate the curve in Fig. No. 3, with the result that for the same starting time a fuel of approximately 150 cetane number would be necessary for an equivalent start. Engines have been started in ten seconds at -10 degrees F. with the addition of small amounts of ethyl ether in the inlet manifold. Although this has not been done in field use, the finding suggests the practicability of a small carburetor which is attached to the inlet manifold and in which small vials of ether may be placed to aid starting under extreme weather conditions. The reason for the effectiveness of this compound is readily understood from the fact that the auto-ignition temperature of ethyl ether is about 350 degrees F., while that of a high cetane fuel oil is approximately 600 degrees F.

The injection of a quantity of fuel in excess of that injected at full load on the engine has also been found beneficial, particularly at the lower cranking speeds. The amount of this excess fuel seems to depend upon the type of engine. For some turbulence chamber types it varies from about 30 per cent to 85 per cent more than full load injection.

## APPLICATION OF HEAT

By far the most successful aid to starting, however, is the application of heat. This may be done in several ways, such as by preheaters, by intake air heaters, and by increasing the heat of compression.

Preheaters refer to devices by which heat may be applied to the motionless engine. Preheating may be accomplished by an electrical immersion heater in the coolant or by a fuel-burning compartment heater which may heat the coolant or directly heat the entire engine. The immersion type preheater offers a considerable drain on the batteries and is not as satisfactory as the compartment heater in over all usefulness. The compartment heater is generally considered the most satisfactory aid to starting in use at the present time because it can keep the whole power unit warm. The batteries thus retain a higher charge, the lubricating oil offers better lubrication and less resistance to cranking, and the over all starting ability of the engine is different from summer operation only in that the intake air during cranking is cold. The fuel oil burning compartment heater may have an electrically driven motor to run its fuel pump and blower, which will, of course, use a small amount of electricity. But the blower will apply the heat to all parts of the engine and the engine compartment, including the lubricating oil system.

It has been found that if a winter hood (canvas cover extending over hood and down to the ground) is put over the engine immediately upon stopping and while the engine still retains a considerable amount of heat, a small wick-type heater placed in the compartment will supply sufficient heat to keep the engine in good starting condition for many hours. This arrangement has been used with good results in weather as low as -40 degrees F.

Heating the intake air has almost become a prerequisite to consistent starting in subzero temperatures. For an engine with any fixed compression ratio, the temperature rise due to compression will be a function of the cranking speed. Consequently, as the ambient air temperature is reduced at a constant cranking speed, the compression temperature is also reduced until at some point this temperature does not reach the ignition temperature of the fuel.

Two separate methods are widely used to heat this air. One is to place electrical "ribbon" coils between the inlet manifold and the intake port, while the other utilizes a

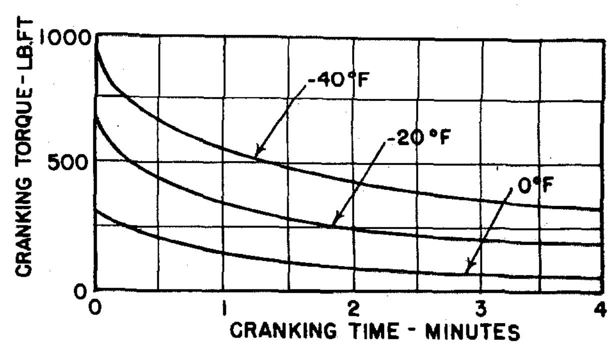

Fig. 1—Cranking torque curves (constant speed, specific lubricating oil).

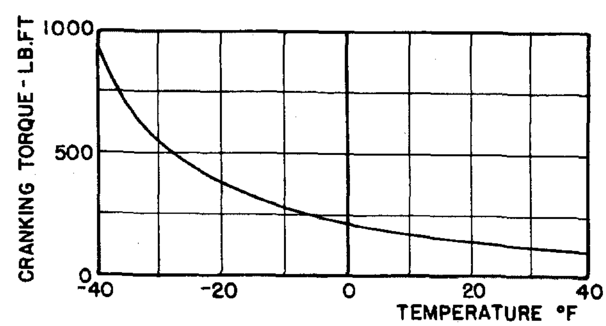

Fig. 2—Cranking torque curve (constant speed, specific lubricating oil).

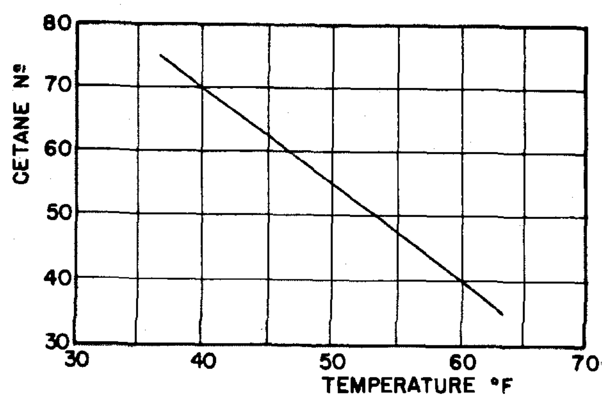

Fig. 3—Cetane vs. temperature (constant speed).

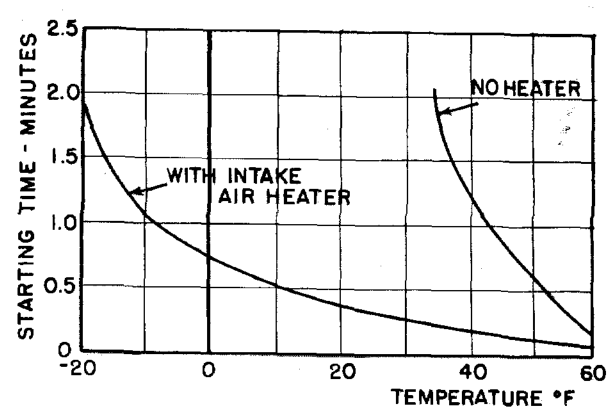

Fig. 4—Starting curves.

fuel oil spray which is burned in the inlet manifold. Both types work satisfactorily, but each also has its disadvantages. In the electrical heater an immense amount of energy must be used to obtain good performance. This electrical input will range up to five or six thousand watts for a medium-sized automotive engine and difficulty is often experienced in keeping the coils from burning out. This is a tremendous drain on any standard sized battery. Also, the coils offer a certain amount of restriction to the inlet air, which is undesirable while the engine is in operation.

The best starting is probably experienced with the use of the "flame-thrower" type of heater. This unit mixes air with fuel and sprays the atomized mixture past a sparking electrode into the inlet manifold. (A blow torch works equally well.) The only difficulty experienced lies in getting enough flame into the manifold to heat the air sufficiently and yet not so much that all the intake oxygen will be burned before reaching the cylinders. Proper adjustment of the unit usually will rectify this problem. This type of unit has been proved quite successful in field use. A typical curve of starting time versus temperature is shown in Fig. No. 4. These curves readily indicate the necessity of the heater.

The last method of applying heat to the aircharge (and probably the least used as far as starting is concerned) is to raise the temperature of compression. This may be done in several ways, which will be briefly noted here as a matter of interest. First, increasing the compression ratio obviously will raise the temperature. However, this is undesirable because of the high peak pressures imposed on the cylinders when the engine is in operation. Another method which effectively increases the compression ratio and which works very well on some engines, is to close the intake valve at "bottom dead center." Most engines have this valve close from 30 to 40 degrees F. "after bottom center" and as a result lose a certain amount of compression. For example, if an engine whose ratio was theoretically 15 to 1 had its intake valve close 45 degrees F. "after bottom center," its actual ratio might be about 12.5 to 1. This would make a considerable difference in the compression temperature.

## CONCLUSION

With all these aids in mind, the final conclusion reached is that the application of heat is necessary for reliable starting. To keep the engine warm is possibly the best solution, so that the cranking requirements will not be great. The weight and size of the starting equipment can thus be reduced. and it is probable that the engine life will be increased by eliminating the possibility of scuffing pistons and cylinders because of improper oil films during the cranking period.

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# Radar's Peaceful Cousin

(*Continued from Page* 11)

interesting, and their solution showed great engineering skill and ingenuity.

## DEVELOPMENT

No one organization is responsible for the entire development of the principle or for the product itself. Pioneer work was done by Dr. W. L. Everitt of Ohio State University in 1928 and 1929. However, the electronic units required to generate the high frequencies necessary were not available at that time, and no commercial model resulted directly from his work. The final development work was done largely by Lloyd Espenscheid and R. C. Newhouse of the Bell Telephone laboratories. The first public demonstration of the commercial product was in 1938. With the threat of war, the equipment was turned over to the armed forces, and the knowhow that had come from its development was applied to research on radar.

The improved instruments that have been developed for the armed forces are based on the same principle as the commercial model. No specific information about them is available. However, it is known that the basic operating principle of this type of radio-reflection instrument is different in detail from the true radar. The difference is significant because the Western Electric type of device operates accurately at much shorter distances than a device based on the true radar principle. Postwar terrain clearance indicators will probably be a great improvement over those in service today, but the principle will be basically the same.

Several improvements were tried on the commercial model, but they were not reliable enough to use in regular operation. Further development will undoubtedly lead to improvements that will greatly increase the usefulness of the instrument. A minimum-altitude warning device is desirable for routine airline flying. Such a device must give a warning when the plane is closer to the ground than a predetermined distance. This feature would also serve as a collision warning. Another desirable improvement would be an increase in the effective maximum reading. At high altitudes there is little need for an instrument to indicate obstructions in a hemisphere below the airplane. By beaming the transmission downward, a marked increase in effective reading can be achieved. The use of true radar at extreme altitudes might provide a practical solution, if the installation does not become too cumbersome. Improvements in equipment should reduce both the weight and the power required. At present the instrument draws more power than light aircraft readily can provide. Weight reductions are possible on all units, and mass-production manufacturing methods should reduce the price enough to make every private flyer a potential owner.

## THE FUTURE

Postwar aviation will not be the infant industry that it was in 1939. It will be a giant, powerful by all the criteria of industrial greatness. And this giant will not be content to grope blindly in the fog or to suspend operations at the sign of bad weather. The technology of radio direction and range finding has advanced to the point where all-weather flying is possible with large aircraft. Light, private aircraft need fear only violent weather. Devices such as frequency modulation ground-to-plane phone, radar, range beams, and instrument-landing radio-glide paths will be at the disposal of commercial aviation in the future. These radio navigation aids all require ground installations and ground cooperation with aircraft in flight. Unlike ground aids, the terrain clearance indicator is a part of the airplane, and it operates without outside assistance. For the private flyer as well as the commercial pilot, the added safety and simplicity that this instrument brings to flying will be of tremendous importance. In the future, the dial of a Terrain Clearance Indicator may well become as familiar as today's speedometer in the family sedan.

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