CHAPTER IV

Investigation of Aviation Fuels by the Army: Industry Cooperation in Meeting Army Specifications, 1928-1932

WHEN the Army began a systematic investigation of aviation fuels under Tillinghast's direction at Wright Field in 1928, a considerable background had already been established by: Ricardo, Tizard, and Pye; Midgley, Kettering, and Boyd; Edgar, the National Bureau of Standards, the Army's own previous explorations, and the CFR. The findings of these investigators and research groups were all available to Wright Field and had considerable influence upon the program. Tillinghast very wisely ruled, however, that the Army should find out for itself and not accept as gospel anything in the welter of conflicting information.

EARLY FUEL TESTING

When studies of knocking properties were started in small single-cylinder engines, the CFR engine was not available at Wright Field. However, a rebuilt Delco farm lighting engine used by the Ethyl Gasoline Corporation for determination of knocking properties had been loaned to Wright Field and was used for the initial work. In the light of current knowledge this engine was appallingly crude for the purpose of testing fuels and used to break crankshafts in less than five hours when operated on fuels of 60 PN and higher. Apart from breakage, the engine operation was often very unsatisfactory and improved operation was sought by schemes which were often nothing better than hunches.

BENZOL BLENDS

Wright Field at this time was working vigorously on Prestone (ethylene glycol) cooling of the Curtiss D-12 engine (see Schlaifer below, p. 667). One day when the Delco engine was operating very badly with water cooling, Prestone was tried on a pure hunch. While operating with water cooling it had been found that 3 cc lead per U. S. gallon in a particular batch of DAG was equal to 50% of the same DAG plus 50% benzol. When the engine was operated with the much higher cylinder temperature that was obtained with Prestone, the benzol blend was no longer equal to the lead blend but was considerably inferior. This was startling and led to further exploration of lead and benzol in both low PN DAG and in high PN California Fighting Grade. The various blends were compared with heptane-octane blends over a wide range of cylinder temperatures. It was found that the PN of DAG-lead blends and of California-lead blends was not affected by increase of cylinder temperature whereas either DAG-benzol blends or California-benzol blends lost PN with each increase of cylinder temperature. The finding in regard to benzol blends served to explain the already observed relative ineffectiveness of benzol in some very hot running air-cooled engines.

Fundamental Importance of Relation of Engine Temperature to Relative Fuel Behavior

The finding in respect to the effect of cylinder temperature upon the relative knocking behavior of fuels was an accident rather than a result of complying with Tillinghast's requirement that the Army should find out for itself. The finding was, however, a very useful accident and was a milestone in guiding the Army thinking for a number of years.

Whether the effect of cylinder temperature upon relative knocking behavior of fuels was known before the Army finding is undecided. Tillinghast regarded the finding as of fundamental importance and personally appeared before the CFR to discuss it, but the CFR almost as a whole appeared either not to understand it or to regard it as of minor importance. The British seem to have been unaware of the effect of cylinder temperature since, upon publication of the data,[1] they raised

[1]S. D. Heron, "High-Performance Gasoline Aircraft Engine," *Transactions of the American Society of Mechanical Engineers* 52, Part I, 1930, pp. 233-253 (AER-52-30).

the question as to whether the effect might be due to peculiar impurities in American benzol which did not occur in British benzol.

The cylinder temperature effects showed that engine conditions could affect the relative value of a given type of fuel. Engines with high cylinder temperature seemed unsuitable for benzol blends which were apparently much more valuable in engines with low cylinder temperature. Such engine types have since become known as severe and mild. Likewise, some fuels showed variation of PN with engine temperature conditions whereas others did not, and such fuels have since become known as sensitive and insensitive types. To the Army, the fact that relative fuel knock properties were a function of the engine conditions under which they were determined indicated that a variety of fuels of sensitive and insensitive types must be tested in complete aircraft engines for determination of knocking properties. It was anticipated that from these tests it would be possible to pick out the most suitable type of fuel and also to set up test conditions in the laboratory engines used to evaluate knocking properties so that evaluation in the laboratory engine would essentially predict behavior in the complete aircraft engine.

Large Amount of Fuel Testing

Starting in 1928 a large amount of fuel testing in complete aircraft engines of both air-cooled and liquid-cooled types was carried out. Curtiss D-12 engines without superchargers and with both Prestone cooling and water cooling were used, and the compression ratio was increased to take advantage of the high PN fuels which were available experimentally. Fuels that were currently considered of high PN did make Prestone cooling more readily usable in the D-12 engine and improved both power output and fuel consumption by about 10% as a result of increased compression ratio. The gain in power output was relatively small, and it is questionable if high PN fuel would have been worth the trouble in unsupercharged liquid-cooled engines except for facilitating the use of Prestone which was giving considerable performance gains since the radiator size was reduced by about 70% (see Schlaifer below, p. 667, n. 3). Tests of a variety of high PN fuels were also carried out in a supercharged Curtiss V-1570 engine (a larger version of the D-12 widely used by the Army in unsupercharged form).

Advantages of Supercharger

While the Curtiss D-12 using water cooling gave remarkable performance on low PN DAG, the large air-cooled engine, such as the Pratt & Whitney Wasp, and particularly the large supercharged air-cooled engine (one of 400 hp or more) was badly handicapped by DAG of about 40 PN. Overheating and mechanical failure of pistons and cylinders were the price of knocking in the large air-cooled engines. The smaller air-cooled engines, such as the Wright Whirlwind, performed satisfactorily on DAG of 40 PN and such fuel remained the Army's standard for training until well into the 1930's.

Special Advantages of the Supercharger on the Radial Engine

In the case of the large radial air-cooled engine the supercharger had three advantages: first, it was the easiest and most satisfactory solution of the difficult problem of distributing the fuel-air mixture; secondly, it greatly improved engine performance at altitude (it was, of course, originally embodied in power plants for this reason); and thirdly, it enabled power output to be greatly increased at sea level and low altitudes. Some of the early superchargers on radial engines compressed the fuel-air mixture only slightly and thus did not appreciably improve altitude performance. However, as altitude performance began to be sought and more mixture compression was embodied in superchargers, engine performance at sea level take-off and low altitude was reduced since increased compression heated the mixture and this caused knocking. Increase in fuel PN avoided the knocking and, if increased far enough, enabled the power at sea level to be increased until it was much higher than that of an unsupercharged engine. The highly (for those days) supercharged engine not only had a great deal more power at sea level than the unsupercharged

engine but might have as much power at an altitude of 10,000 ft as the unsupercharged engine did at sea level.

Doubled Output of the Pratt & Whitney Wasp with Supercharging and Better Fuel

As an example of the gains in output, which were made possible by supercharging and fuel of higher PN, Wright Field early in the 1930's obtained about 900 hp for very short periods from the Wasp which started its career in 1926 at 400 hp[2]. On the whole it may be said that the supercharger was the most important factor in pushing the development of high PN fuels.

The test program of available fuels in complete aircraft engines covered mild (water-cooled) and severe (air-cooled) engines and both sensitive and insensitive fuels. Rightly or wrongly, it was decided by Wright Field that the requirements of the air-cooled engine should control fuel requirements as a whole and this dictated the use of insensitive fuels.

Choice of Fuel Components

The choice of fuel components in 1928-1929 was limited and essentially consisted of benzol, straight-run gasolines of 35 to 55 PN, cracked (olefinic) gasolines of up to 50 PN, and lead. Benzol could not be used in greater than 20% concentration without causing the gasoline to freeze in cold weather, and in addition it was considered to be insufficiently available. (In World War II daily benzol production in the United States was only 2% to 3% of the maximum United States output of aviation fuel of all types.) Benzol, however, was extremely useful as a test fuel and played a large part in the program of determining the best type of fuel for the current engines. Cracked gasolines were found to be sensitive like benzol blends and gave less increase of PN due to lead additions than did the straight run types.

Army Plan to Use Lead

The result of the Wright Field investigations was the decision that California Fighting Grade gasoline plus lead was the

[2]See also p. 626 ff, Superchargers and Propellers.

best answer to the fuel problem. Major C. W. Howard, then Chief, Engineering Section at Wright Field, called a conference of the engine and petroleum industries and told of the Army plan to use high PN gasoline containing lead in general service. He stated that the Army knew that a great deal of operating difficulty would result from the use of lead in respect to valve and spark plug troubles and cylinder rusting. Howard stated that the Army believed that the gains in performance resulting from fuels of high PN warranted the lead difficulties which the Army believed could be overcome. Some of the engine companies were fearful of the lead difficulties and were not enthusiastic about the program. The oil industry accepted the responsibility of supplying a new fuel with only minor opposition.

Army Specification Using Octane Number

Wright Field proceeded to prepare a specification calling for a Fighting Grade gasoline of 68 PN (87 octane number) and requiring that the knocking properties be tested in an Ethyl knock test engine. The knock test engine was chosen because of its availability. The engine operating conditions specified differed from those used in the same engine for motor gasoline (the petroleum industry defines gasoline used in automobiles as motor gasoline) but were known not to be sufficiently severe for sensitive fuels. They were, however, the best compromise possible in the light of availability of equipment. This specification, U. S. Army Specification Y3557, was first issued in March, 1930, and is believed to be the first for aviation fuel embodying a requirement for knocking properties expressed in octane number. It was also the first fuel specification to require Prestone cooling in the laboratory knock test engine as a means of obtaining a controlled cylinder temperature in excess of that which could be obtained with water cooling. It was known that the knocking property requirements could be met by good California gasoline plus 2 or less cc lead per U.S. gallon. Since the availability of such a high grade of California gasoline was somewhat uncertain, however, a lead concentration of 6 cc was permitted. It was known that the lead concentration was too high, and it was intended to reduce it after the

industry response to the specification had been determined. It was soon found that lead could be reduced to 3 cc and that with this concentration there would be no restriction of supply even though base gasolines not originating in California were drawn upon. The supply authorities of the Army refused to allow reduction of lead concentration, and it was not reduced to 4 cc until 1939 or 1940, at which time the PN had increased to 76 (91 octane number) and the Army and Navy were preparing joint specifications for aviation fuels. Specification Y3557 represented an effective increase of at least 40% in PN as regards use in air-cooled engines over any aviation fuel then purchased with knocking property requirements. Before this both the Army and the Navy had been obtaining some fuel of better than 68 PN by adding lead to gasoline which was purchased with or without knocking property requirements for the fuel before addition of lead. While some of this fuel so blended was better than 68 PN, much of it was unquestionably a great deal worse.

Oil Industry Meets Needs

While Specification Y3557 was first issued in March, 1930, fuel procured to it did not go into general service until 1931. It was anticipated that there would be much difficulty in bringing the original batches of fuel supplied up to the PN of the specification. No such difficulty occurred, however, and the oil industry demonstrated its ability to manufacture and supply such a new product with satisfactory control when the industry was convinced that there was adequate reason for requesting it. Transportation to the mid-continent areas made California gasoline a decidedly uneconomic product (e.g., about 8 cents per gallon by tank car to Chicago) and the oil industry rapidly found sources in Texas and Louisiana, which produced gasoline as good or nearly as good as the California fuels.

Difficulties with Leaded Fuels

With general service use of 68 PN fuel, difficulties due to lead occurred on a large scale. The difficulties were not confined to the engines but also occurred in the airplanes. Many airplanes with fabric-covered structures caught fire, and some all-metal aircraft experienced fires in upholstery. These fires were due to corrosion of the exhaust systems caused by lead. This corrosion resulted in hot particles being thrown onto the wings and other surfaces when the airplane was on the ground and when airspeed over the wings was very low or nonexistent. At this time exhaust pipes were made of steel similar to that used in automobile bodies and a change to stainless steel cured the trouble.

Many engineer officers in the operating squadrons roundly condemned leaded fuel as a result of much engine trouble and the necessity for very frequent engine removals from the aircraft in the case of some engines. Verbal suggestions of bribery of the Wright Field personnel responsible for putting leaded fuel into general service were not unknown by harried engineer and maintenance personnel. The Liberty engine then used on a considerable scale gave a lot of difficulty with exhaust valve rusting and sticking with leaded fuel, and some squadrons obtained permission to revert to DAG and did so. Later investigation by Wright Field personnel showed that some of these squadrons had quietly resumed the use of leaded fuel on the grounds that leaded fuel eliminated cracked and leaking water jackets, and that the valve difficulty could be overcome by hand oiling prior to leaving the airplane inoperative for more than two hours. Nevertheless, difficulties due to lead were a pronounced problem, and the engine manufacturers were deeply involved in the troubles they had anticipated.

Demand for Lead-Free High PN Fuel

Some time after the formation of the Aviation Fuels Division of the CFR[3], Arthur Nutt, then Vice President of Engineering, Wright Aeronautical Corporation, and Chairman of the AFD, led a movement to secure 68 PN gasoline which would not contain lead and which would be available on a large scale for both airline and military use. D. P. Barnard of the Standard Oil Company (Indiana), who was a member of the AFD Sub-Committee on Test Programs, repeatedly pointed out to Nutt that 68 PN leadless aviation gasoline could be produced but

[3]See below, p. 600.

that it would cost more than 5 cents a gallon which was then about the price of 68 PN leaded aviation gasoline f.o.b. oil refinery. This controversy persisted for some time, and reference is still occasionally made to "Dan Barnard and his — — nickel a gallon." Nutt's movement came to nothing, but it is of interest that the gasoline he asked for is currently available as the base fuel used to make the leaded Grade 115/145[4]. Much engine development was initiated, some by the engine manufacturers with Army financing and some by the engine manufacturers out of their own pockets. Some of the development was due entirely to lead and would have happened without change of engine output. The greater power output made possible by a combination of a better base gasoline and lead necessitated improved cooling and engine strength. The major items of the necessary engine development will be summarized below.

It is probable that the service use of leaded gasoline would have been discontinued except for the farsightedness and dogged determination of Major Howard who consistently pushed and supported the program.

[4]See below, pp. 651 ff.