C.) Knock Determination.

(a) Methods.

(I) Octane Number Determination . - The small mono-cylinder engines used in Germany for this work were the standard C.F.R. knock rating engine and the German I.G. engine. Automobile fuels were originally rated by the C.F.R. Research Method, but from 1st. April, 1943, the Army adopted the C.F.R. Motor Method as corresponding better with operating conditions in military vehicles.[93] Day to day control of aviation fuel production was made using both the I.G. and C.F.R. engines operating according to the C.F.R. Motor Method. For the determination of the practical knock limit, however, rating of aviation fuels under Motor Method conditions was known to be too severe for all but highly paraffinic fuels. Thus the I.G. Oppau Method was developed in Germany having milder test conditions corresponding to the C.F.R. Research Method.

The operating conditions in the Oppau Method are :-

(I) Speed	600 RPM (as in Research Method)
(II) Ignition	22° BTDC
(III) Coolant Temperature	100°C (as in Research Method)
(IV) Mixture Temperature	125°C

(V) Inlet Pressure 1000 mm Hg.

(VI) Carburettor setting variable between

$\lambda = 0.7$ and 1.2.

The Oppau Method is a multipoint one but is simpler than the supercharging method in the BMW 132 N cylinder with which, however, it is in reasonable agreement.[71] It was reported[69] that, in general, rich mixture running has a greater influence in the BMW than in the I.G. engine.

With routine tests by the Oppau Method, the knock behaviour is read off the octane number dial. This is quicker than bracketing each fuel sample between two reference blends. Of course, the octane number dial has been calibrated previously with reference blends at mixture strengths always corresponding to maximum knock.

The method of test is to vary the compression ratio until incipient knock occurs (knockmeter reading 50), with the carburettor adjusted to the strongest knocking mixture ($\lambda \triangleq 1$). The knock behaviour is then read off the octane number dial. The mixture strength is changed and the knock decreases. To restore it to its original value (knockmeter reading 50) the compression ratio is raised. Thus another octane number is obtained. From six to eight such octane numbers an octane number vs λ graph is plotted.

Under the conditions described, this method was found [72] unsuitable for testing unleaded fuels, or fuels with particularly high benzene or alcohol contents.

(2) Supercharge Testing. - The failings of single point methods, such as the C.F.R. methods of octane number determination, for evaluating the behaviour of a fuel in an aero engine are well known. Seeber [68] has outlined these. Correlation between small engines, like the C.F.R., and full size engines was also found difficult. A method was therefore adopted by the D.V.L. of examining aviation fuels in a single cylinder aero engine under conditions approximating as closely as possible to the actual stresses on the fuel in the full sized engine. The test conditions finally employed in the D.V.L. Supercharge Method are given in BIOS Final Report No. 119 as -

(I) Speed 1600 RPM.

(II) Intake air temperature 130°C supercharged

(III) Valve overlap 40°

(IV) Cooling air pressure 300 mm Hg.

(V) Oil temperature 90°C

(VI) Cylinder Head Temperature 240 - 250°C maximum

(VII) Ignition 35° BTDC

The variable in this method is the boost pressure, which is provided by an externally driven compressor. As the mixture strength is altered, the boost pressure is varied to give the same knock. (6 - 10 knocks/minute by ear). A knock limit curve is thus obtained by plotting these values of boost air pressure as a function of air/fuel ratio. The knock limit curve may also be drawn in the form of mean effective pressure as a function of air/fuel ratio.

An attempt was made [56] to develop a supercharge method using a small motor, which would give results agreeing with those obtained by the D.V.L. Supercharge Method using the BMW 132 cylinder. The N.S.U. 501 O.S.L. motor was used for this purpose. The order of rating fuels in the BMW and NSU engines was the same, but the knock limit curves obtained with the NSU engine were flatter and closer together. Also, the highest mean effective pressures obtained were below those obtained with the BMW engine because the NSU engine was not designed for the test conditions used.

Other small supercharged engines, also, were developed on the principle of the D.V.L. Supercharge Method in the BMW 132 cylinder,[86] and tests were made[84] on the I.G. engine, in which the compression ratio was kept constant and the boost pressure was varied.

In 1944, Witschakowski[87] reported supercharging tests made in a D.B. cylinder and a BMW 132 cylinder. Instead of the usual conditions of the D.V.L. Supercharge Test, the conditions used corresponded more with main engine operation. From these tests it was concluded that a number of aviation fuels used at that time were not being exploited to the full in the existing aero-engines.

(3) Main Engine Tests. - In BIOS Final Report No. 532, fuel rating in full scale aero

engines was reported to be little advanced in Germany as the results with the D.V.L. Super-charge Method in the BMW 132 N cylinder had proved sufficiently reliable.

<u>(b) Accuracy of knock determination.</u>

(I) Octane Number Determination. - From 1936 to 1943 a series of investigations were made by the various German test laboratories to ascertain the accuracy of octane number determination.

In 1940, Wilke [81] compared U.S. and German results and attributed the poorer accuracy obtained in Germany to lack of experience, the use of both the C.F.R. and I.G. engines, lack of standard sub-reference fuels and the wide range of synthetic fuels tested. He gave the value of ± 1 Octane Number as the mean error for the C.F.R. engine, under both Research and Motor conditions. Using the I.G. engine and its octane number dial, the mean error, as determined with the use of reference fuels, in the same engine, was ± 1.27 Octane Numbers.

From 1940 to 1941 the main purpose of the research group was the unification of sub-reference fuels and transfer graphs for octane number evaluation. Singer and Wilke [70] have reported on this. For secondary reference fuels I.G. standard gasoline (replacing heptane) and the purely paraffinic fuel "Z" (replacing iso-octane) were introduced. All testing stations used one calculation graph instead of individual curves for standard gasoline and standard reference fuel "Z", and the limit of accuracy for a storable petrol was found, over a large number of engines, to be ± 1.5 Octane Numbers. It was thought that by using heat sensitive and heat insensitive fuels some idea of the heat standard of the engine would be gained. However, it was found that the spread of points hardly changed when a heat sensitive or heat insensitive fuel was used. The accuracy of blending values (i.e. blending octane numbers) was reported as ± 4 Octane Numbers. Neumann [47] reported that the I.G. test motor gave values of 0.8 and 0.4 Octane Numbers less than the C.F.R. Research and Motor Methods respectively. He also commented on the considerable spreads obtained in the knock measurement of synthetic fuels, and mentioned that better results are obtained when a reference fuel similar to the fuel under test is used.

The position of German knock measurement after the completion of the 10th series of investigations was discussed at the conference of the Knock Panel at Oppau in 1943. [93] Sixty laboratories with one hundred and eight test engines took part in the investigations, in which four automobile petrols and four aviation petrols were rated according to the Research and Motor Methods respectively. In both methods the average accuracy was ± 0.6 octane numbers, 82% of all the results falling within the previously accepted limit of ± 1 octane number. For the Research Method the measured value in both the I.G. and C.F.R. engines was on the average equal. In the Motor Method the value for the I.G. engine was on average approximately 0.3 octane numbers lower than with the C.F.R. engine. However, this difference lay within the known limits of accuracy. These limits of accuracy did not apply to synthetic fuels. For example, Fischer-Tropsch gasoline, although giving better reproducibility when the secondary reference fuel "Z" was admixed, still gave greater variations than normal gasoline. Such variations had been suggested as due to

(I) Effect of some physical difference in the composition of the petrol (e.g. due to vapourisation losses in storage and handling).

(II) Effect of some chemical influence (e.g. peroxide formation).

(III) Effect of peculiarities of individual test engines, and in method of measuring to which synthetic petrols react in some special way.

Even when precautions were taken to eliminate the effect of (I) and (II), ratings still gave average variations of ± 1.2 and ± 1.4 octane numbers.

It had been previously thought [33, 47] that knock measurement was more reliable the more the reference fuel resembled the fuel under test. Three benzol blends, however, were rated by different test laboratories using

(I) Reference fuels i - octane and n-heptane.

(II) Secondary reference fuels benzene and I.G. standard gasoline.

(III) Secondary reference fuels "Z" and I.G. standard gasoline.

The assumption that the reference fuel must conform to the fuel under test was not established. It appeared that secondary reference fuel "Z" would be suitable for all types of samples.

(2) D.V.L. Supercharge Method - Wenzel [78] considered that the limits of error laid down in the regulations of 1940, namely $p_{me} \pm 4\%$ and charge pressure $\pm 1.5\%$ were too stringent.

Making tests on different days seemed markedly to affect results.

He concluded that, using the simplified D.V.L. procedure (constant spark advance), even with the greatest precautions, limits of error of less than $\pm 5\%$ could not be expected.

A detailed consideration of the spread limits of supercharge curves in a single test engine was made by Seeber [67], in which fuel side influences and the influence of experimental technique were differentiated. He also presented data obtained on the reproducibility of knock limit curves using identical fuels in several test engines, and concluded that, even where several motors are used, the following error limits should not be exceeded :-

p_{me} ± 2% for paraffinic and isoparaffinic fuels

p_{me} ± 4% for aromatic fuels (those containing more than 35% of aromatics or unsaturated hydrocarbons).

If greater errors occurred in spite of all control and experimental precautions, he recommended that the cause of the errors should be investigated by use of the D.V.L. pressure acceleration procedure.

It appears that even these error limits may have been too strict, and BIOS Report No.119 gives the reproducibility of performance curves as to within 4 - 6 %.

Penzig [50] showed that better reproducibility could be obtained by using liquid cooled cylinders. Ease of repeatability was also greater the flatter the knock limit curves.

Witschakowski [83] suggested that for ordinary fuel testing the simplified procedure was adequate since any advantages of variable ignition are annulled by poor repeatability. He also stressed the necessity for identical engine details if good comparability between several test engines were to be obtained.

The importance of using the lubricating oil specified for the supercharge test was apparent from investigations made by Franke.[19] He found that, under D.V.L. supercharge conditions and also under main engine operational conditions, the lubricating oil had an effect on the anti-knock value of a fuel. The magnitude of this effect was dependent on the aromatic content of the fuel, and only became appreciable for fuels with a high aromatic content. It appeared, however, that the lubricating oil had no effect on the lead susceptibility of a fuel.