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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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No. 62

THE PROBLEM OF FUEL FOR AVIATION ENGINES.

Lecture given by Professor Kutzbach, of Dresden,
Scientific Collaborator of the Adlershof Aeronautical Laboratory.

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THE PROBLEM OF FUEL FOR AVIATION ENGINES.*

The speaker began by mentioning the physical properties which may be demanded of fuels for aviation use and the means that may be adopted by the engine manufacturers to properly meet the demands necessitated by the use of such fuel.

In the choice of a fuel the following factors must be considered: (1) its composition; (2) the quantity available; (3) the price per heat unit; and (4) the possibility of keeping stocks in aerial ports both at home and abroad. It is also important to know if the change from one fuel to another will necessitate any serious modification of the engine. With the present universal scarcity of gasoline, the day will certainly come when heavier fuel will have to be considered.

The storing of fuel in the airplane and supplying it to the engine are other points to be considered. Gaseous fuel, which would have to be taken on board in large gas bags or in air-tight cylinders, cannot be considered as the primary fuel on account of the space occupied by and the weight of such containers. At best it might be carried in liquid form in heat-proof containers. Solid fuels which might be pulverized or are in the form of powder (explosive material) cannot be considered, although liquefiable or soluble fuels such as napthaline or par-

* Lecture given by Professor Kutzbach, of Dresden, Scientific Collaborator of the Adlershof Aeronautical Laboratory.

affin might be used. Liquid fuels of high calorific value per unit of weight are best adapted to the purpose. Such fuels are the saturated and unsaturated hydrocarbons which not only have a high calorific value per unit weight but which may be easily supplied the engine in a very fluid state. Considering the fact that airplane engines must be capable of operation near the ground in the intense heat of summer and also at high altitudes in the severe cold of winter, the question of fuel supply is not of the simplest because many fuels lose their fluidity at extremely low temperatures. Special measures must therefore be taken so that at least the portion immediately required for the engine may be kept in a very fluid state either by heating with hot water, hot oil or electrical energy.

One of the most important points to be taken into consideration is that of ensuring the safety of the fuel from ignition in case of leaks in or injury to the tanks and connecting pipes such as may occur in forced landings. This brings out a property demanded of the fuel by the manufacturers of airplane engines, namely the possibility of quickly and easily supplying to the engine a good combustible mixture without the necessity for preparing such a mixture at a temperature or pressure other than that of the free air at the altitude at which the engine is operating. An ideal fuel would be of such a nature that it does not evaporate instantaneously in free air or at least does not form a mixture that ignites easily, but which can be mixed and gasified satisfactorily in the carburetor and will form a suffic-

iently inflammable mixture in the engine cylinder.

These conditions have not yet been fulfilled. Apart from insuring the safety of all the fuel pipes by double tubes and double jackets, they might be met satisfactorily in two ways. In the first of these use could be made of an explosive fuel that evaporates easily, such as gasoline or benzol, supplied in such a manner that there is no possibility of delivering fuel to the engine in excess of its instant requirements. For this purpose the fuel in the tank would have to be condensed to such an extent or kept at such a low temperature that it resembles an ointment in fluidity and will not flow out of a leaky tank or it might be absorbed by some special substance to prevent its escape. In the second way, fuels could be used that do not readily gasify, i.e., fuels with high boiling points and flash points. The carburetor would be so designed or the intake air and fuel would be brought to such a condition in the manifold or in the cylinder that mixing and ignition would be satisfactory. The important question of the utilization of fuels of lower inflammability and consequently of higher boiling point and lower cost would thus depend on the engine.

The preparation of the fuel mixture in the carburetor was then discussed. The carburetor functions primarily as an ejector pump as shown in Fig. 1. The following equation (1) expresses its metering relations

$$\frac{W_a}{W_f} = \frac{A_a}{A_f} \sqrt{\frac{D_a}{D_f} \frac{P_a}{P_f}}$$

W_f and W_a signify the weight of the fuel and of the air respectively and should preferably be used as a clearly defined ratio, usually in airplane engines one giving a slight excess of air or of fuel; A_f and A_a the cross sectional areas of flow; D_f and D_a the densities of fuel and air at the mixing point; and P_f and P_a the pressure drops at the nozzles in millimeters of water. The air velocities are only indirectly stated in this equation in the value D_a which falls very slowly with increasing values of r.p.m.

In changing from one fuel to another, the fuel nozzle A_f must be so altered that the new fuel requirement W_f of air shall be proportional to the square root of the density D_f. The ratio of the two areas would therefore be given by equation (2)

$$\frac{A_f''}{A_f'} = \frac{W_f''}{W_f'} \sqrt{\frac{D_f'}{D_f''}} \qquad (2)$$

when W_f' or W_f'' represents the weight of completely burnt fuel in chemically combining proportions with unit weight of air.

We further see by equation (1) that the mixture ratio changes with change in altitude of flight as D_a diminishes as the altitude increases, while D_f remains unchanged in the case of liquid fuel. $\frac{W_a}{W_f}$ would therefore decrease as $\sqrt{D_a}$ with increased altitude, and the engine would therefore consume more and more fuel unless preventive measures were taken. The influence of temperature is likewise expressed in D_a so that the mixture would be richer in warm weather; that is, with reduced air density.

It is especially important that any possibility of separation of the fuel and air, either in the manifold or cylinder, should be prevented. There are two fundamental ways of doing this:

1. By the finest possible atomization, whatever the load and engine speed may be. This has been proved by experience to be accomplished by high air velocities and low fuel viscosities.* Atomization with slow engine speed may often be found difficult.

2. By vaporization of the whole or the main part of the fuel, so that there is no longer any possibility of its separation from the air.

There is no object to be gained, however, by the vaporization of the fuel before the fuel nozzle except in the case of liquids having a very low boiling point, such as liquefied illuminating gas, methane, etc. The boiling point of the ordinary engine fuels is too high at atmospheric pressure. (See Fig. 2.) Fig. 2 gives distillation curves of pure and mixed fuels from various sources. At atmospheric pressure the boiling point is far higher than atmospheric air temperatures. When light gasoline is used, provision must be made for adequate cooling at high altitudes, as it would otherwise attain boiling point on account of the low air pressure, thus deranging the formation of the mixture and causing the engine to stop working.**

For liquid fuel the vaporization therefore best takes place after leaving the fuel nozzle when it is surrounded by the air

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* See Note I.

** See Note II.

for combustion which must also supply the heat for evaporation.* As about 12 1/2 m.^{3} (441 cu.ft.) of air combine with 1 kg. (2.2 lbs.) of gasoline or petroleum, the volume of the gasoline vapor is only about 1/50, and that of petroleum only 1/200 that of the air, so the partial pressure of the fuel vapor is therefore only 1/200 of the atmospheric pressure; and the process of evaporation takes place more easily than without such low partial pressures of fuel vapor.

The quantity of liquid fuel passed through the nozzle therefore evaporates extremely rapidly in the air in consequence of its low partial pressure, - the boiling point being considerably lower than with atmospheric pressure - and continues until the saturation point of the air is reached. The air is more or less saturated after the evaporation of the fuel, depending on the boiling points of the fuel, its vapor volume and the temperature of the air. The curves in Fig. 3 show that with hexane air is saturated at -18° when there is the quantity of hexane (the principal component of gasoline**) necessary for good combustion, so that when the air is cooled about 30°C by evaporation, air of about +15°C suffices to bring about complete vaporization.*** The intake air at +15°C is at first entirely free from fuel; it then evaporates rapidly, cooling and increasing the fuel content of the air at the same time. At -15°C its percentage of saturation amounts to 85 per cent when the entire fuel needed for combustion has evaporated.

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* See Note III.
** See Note V.
*** See Note IV.

Similar values are given in Fig. 4 and in Table 1 for hexane, benzol, ethylalcohol, decane (a component part of petroleum) and naphthaline, the approximate boiling points at atmospheric pressure are also given.

TABLE I.

Fuel	Boiling point.	Saturation temperature of the fuel mixture.	Drop in temperature due to evaporation.	Temperature of the air for complete vaporization higher than
Hexane	70°C	-18°C	30°C	15°C
Benzol	80°	- 5°	30°	30°
Ethyl Alcohol	78°	+22°	110°	135°
Decane	160°	+42°	35°	80°
Naphthaline	220°	+92°	40°	135°

In the case of alcohol, the cooling of the air is remarkably great, chiefly because of the small amount of air in the combustible mixture, and the high latent heat of vaporization which must be supplied by that small quantity of air. Only fuel mixtures with a temperature sufficiently higher than the saturation temperature can be entirely vaporized in the short time available and thus be insured against any separation of fuel and air. Below the saturation temperature, part of the fuel is always in the form of fog or small droplets, and the larger the drops the greater is the possibility of the separation of the fuel.

If, however, all the walls of the pipes and of the combustion chamber be maintained at temperatures above that of satura-

tion by the aid of the natural heat of the machine, of the heat of cooling water or of the exhaust, the risk of the separation of the mixture is sensibly diminished.*

There are two methods of using fuels with high boiling points, either or both of which may be applied separately or simultaneously: first, by atomizing the liquid as finely as possible at all loads; and second, by increasing the temperature of the fuel mixture and walls above the saturation temperature of the fuel-air mixture.

This increase in the temperature of the mixture and walls is difficult when starting the engine cold as it requires time to obtain heat from some source and transfer it to the mixture. The most convenient method is to start with fuel of a low boiling point and run until the desired temperatures are attained. There is one great disadvantage to be considered in the increase in temperature of the mixture, namely, the great difference in the heat supplied by the engine at different loads. In the case of the airplane engine, which is almost always fully loaded, this disadvantage is fortunately of no great importance.**

The first consequence of the increased temperature of the mixture and walls is a reduction in volumetric efficiency, E_v and likewise of the mean effective pressure of the engine, due to the decreased density of the air. The following equation gives the mean pressure:

$$P_m = \frac{427 \cdot E_t}{10000} \cdot H \cdot E_v \text{ ***} \quad \ldots\ldots (3)$$

in which E_t indicates the thermal efficiency, and H the heat-

* See Note VIII
** See Note IX
*** See Note X

ing value of a unit volume of the mixture. If the air be adequately heated so that the mixture enters the cylinder at its saturation temperature, an alcohol mixture would have to be 27° warmer than one of gasoline since the saturation temperature of the former is +22°C while that of the latter is -5°C. This increase in mixture temperature would result in a 10 per cent loss of air weight at full throttle. A naphthaline-air mixture at 92° would give a greater loss. In both cases there is a loss of intake oxygen, of E_v and consequently of power. The higher the saturation temperature of the mixture as for gas-oil and heavy tar oils, the higher the point to which the preliminary heating must be carried.

It would obviously be a good plan to transfer the process of mixing to the combustion chamber itself, in order to heat the walls of the combustion chamber and also the fresh air supply in the shortest possible time. This would, however, necessitate the rejection of the simple yet marvelously effective air ejector as an atomizing and mixing device, and its replacement by a compressed air atomizer or even by the simple spraying of the required amount of fuel by means of a special pump. The less effective the atomization, the longer will be the time required for vaporization, and as vaporization must be finished before ignition begins, the unfavorable atomization must be compensated for by greatly increasing the temperature of the air.

This is particularly evident in the case of engines ignited by incandescence, the air into which the fuel is injected being

heated to an unusually high temperature through the red-hot, or at least extremely hot, uncooled walls. It is certainly possible to utilize all kinds of fuel with a high boiling point in these engines, but there is a great disadvantage in the unfavorable cylinder efficiency and in the after-burning of the fuel, which is too slowly vaporized and poorly mixed. For these reasons, the solution offered cannot be considered satisfactory.

The lecturer went on to say that he had personally tested the possibility of utilizing fuel with a high boiling-point by means of injection into the combustion chamber with compressed air atomizers, and that such injection could be made at any moment desired. The results showed the operation of the engine to be least reliable when injection was completed just before the ignition, although the air in the engine was then at the highest temperature. The operation was satisfactory only when injection took place while air was being taken in, in which case the prolonged period of carburetion and the stronger air currents certainly caused favorable effects. (In the case of two-stroke engines, injection can take place only during the process of scavenging or compression.) The compressed air can be used for atomization or the air can be supplied at a higher velocity, by Bellem and Bregeras' process,* by using a very much reduced pressure in the combustion chamber during a portion of the intake stroke. By these methods there are still various possibilities of rendering fuels with a high boiling point utilizable without

* See Buchner's Notes on the Benzol question; Fig. 39 in the "Automobile Rundschau" 1913, and Heller's Petroleum Driving Force in Automobiles, Z. d. V. d. Ing. 1919, p.778.

the great disadvantage of a marked rise in temperature outside the combustion chamber itself.

The increase in the temperature of the mixture during the intake stroke entails another disadvantage besides the reduction of volumetric efficiency, namely, that of very considerably increasing the average temperature during the whole cycle, particularly the temperature during compression. This is a very great disadvantage as it increases the risk of premature ignition in the mixture.

With regard to premature ignition itself, too little is known about it at present to enable us to give a clear and unbiased judgment as to its cause. The results that have been obtained present many facts tending to general enlightenment, and the engine itself shows most readily how it is affected by fuels and temperature.

The influence of the initial temperature of the mixture on the maximum temperatures at the conclusion of compression is shown in Fig. 5. If the compression ratio is 1 : 5, the compression temperature amounts to about 300°C, 500°C or even 700°C with initial temperatures of 0°C, 100°C, or 200°C. Supposing the limit of admissible compression temperatures to be about 400°C, the compression ratio must be reduced in proportion to the increase in the initial temperature. Experience has shown, however, that totally different degrees of compression are necessary in one and the same engine for different fuel mixtures; that the shape of the combustion chamber, the temperatures of the badly

cooled parts, such as the piston, the exhaust valves and the spark plug, and the freedom of the top of the piston from carbon deposit have marked effects. In conclusion, we may say that the risk of premature ignition decreases as the weight of charge is reduced, although the compression ratio which determines the temperature at ignition and the composition of the mixture are not thereby altered.

Tests so planned that liquid fuel was brought into contact with air in an electric furnace* in which the temperature could easily be regulated were carried out at the Augsburg Nuremburg Machine Fabrik by Dr. Holm at request of the lecturer. In Fig. 5 the spontaneous ignition temperatures found by means of this somewhat crude method are given. They enable us to draw comparisons and form conclusions with regard to the action of the fuels in engines. They confirm experience which shows that engines with benzol and alcohol are generally far less inclined to premature ignition than with gasoline.

They show also that petroleum and gas-oil, for which the temperature must be raised when they are utilized in the carburetor, possess particularly low spontaneous combustion temperatures, so that there are two reasons for using a low compression ratio with these fuels.

As the thermal efficiency decreases with reduction of the compression ratio, petroleum and gas-oil appear to be most unsuitable for use with a carburetor, and tar oil very well suited.

* See Dr. Holm's article in the "Zeitschrift f. angew. Chemie" (Journal of Applied Chemistry," 1913, p.273.)

Another difficulty arises through the fact that not only the principal fuel, but also the lubricating oil used may turn the scale in causing spontaneous ignition. Hopkinson* made a remarkable test with an engine using ordinary gas, in which he tried to bring about premature ignition with the aid of a red-hot plug, the temperature of which he measured with thermo-elements. It was not until the temperature of the plug was 600° to 700° that premature ignition took place. If a drop of lubricating oil fell on the plug or on the exhaust valve, a temperature of 400° sufficed for spontaneous ignition. The difficult question as to what part is played by lubricating oil in spontaneous ignition, reminding one of spontaneous ignition in air compressors, here plainly crops up again.

An essential provision for the safe operation of engines with prepared fuel mixtures ignited in the engine by means of a special ignition pin is that the compression temperature should remain far lower than that of spontaneous ignition under all conditions. By selecting suitable fuel and suitable lubricating oil, it is certain that several important economical advantages might be attained. The first step necessary would be the systematic investigation of the properties mentioned, namely, the boiling points, saturation and spontaneous ignition temperatures of fuels considered usable, and the effect of these characteristics on the performance of the fuel in the engine.

If, as in the case of gas oil and petroleum, the spontan-

* See Proceedings of the Institution of Civil Engineers, 1909.

eous ignition temperature is so low that the engine can probably not be operated economically on account of the low compression ratio, all that remains is to undertake the mixture of the fuel and air immediately before ignition, allowing the mixture to burn like the flame of a gas burner in the air, as was done by Oechelhauser in the case of ordinary gas engines. Diesel applied the process to petroleum and gas-oil. In this way all risk of advanced ignition is avoided, and it becomes possible to increase the degree of compression as desired, and thereby the thermal efficiency. These combustion engines, as the lecturer termed them, in contradiction to ignition engines fired by means of an electric spark, were so designed that the finely atomized incoming fuel meets with fresh air of a temperature far higher than its spontaneous combustion temperature and is, therefore, very rapidly vaporized and burned. The test data given by Holm in Fig. 5 explains the fact that to insure spontaneous ignition of tar oil, the fresh air must be hotter than is needed for gas oil. The combustion engine, however, has the peculiarity that it is impossible for the entire weight of fresh air to be used in the combustion in the short time available. It must, therefore, work with an excess of air, and consequently with lower mean effective pressure. This is occasioned by poor atomization (in engines ignited by incandescence it is usually particularly bad), by the incomplete utilization of the air, and by the increased ratio of piston velocity to ignition velocity.

The lecturer then alluded briefly to the importance of the

question of ignition velocity, which plays an important part in the case of high speed engines in particular, and which is as yet insufficiently understood. The well-known researches made at Dresden, by Nagel, Neumann and Nusselt, in burning cold mixtures in a bomb should be extended to as many different fuels as possible. Fig. 6 shows the ignition velocities of various fuel mixtures, set down in terms of the calorific values of the fuel contained in the cubic meter of the mixture, on the basis of Nagel and Neumann's measurements. The values are, like Holm's measurements, most instructive as comparative values. The ignition velocity of the hot mixture in the engine itself is far higher. The so-called limits of the ignition of different fuels (according to Eitner) are also given in Fig. 6. They accord fairly well with the ignition limits obtained in the bomb. The calorific values of mixture ratios giving rise to the greatest development of heat in the engine and to the maximum value for the formation of CO_2 are important. This thermal value varies from 700 to 900 gram calories per cubic meter (45 to 59 B.t.u. per cubic inch), according to the heating value and the amount of air required by the fuel; it is a decisive factor in determining the highest possible mean effective pressure (see equation 3) and consequently of the maximum power of an engine with the fuel in question. As the ratio of air to fuel increases, the ignition velocity first increases slowly, then, in the case of some few fuels, as for instance, ordinary gas, it increases rapidly; in other cases, especially with gasoline and benzol, it falls slowly. For the en-

gine, however, the ignition velocity must not be too low, lest after-burning and delaying explosion take place; nor must it be too high, lest the rapid combustion give rise to too violent explosions. With increasing piston velocities, it must, or may be higher. The limits of the ignition velocity utilized in the engine are about 1.5 to 2.5 m/sec. (5 to 8 ft. per sec.) and therefore at these ignition velocities, the thermal value of the mixture would be highest with gasoline, and lowest with hydrogen. This also explains why the highest mean effective pressure ever attained, between 9 and 10 kg/cm^2, (128 to 142 lbs. per sq.in.) was to be found in the gasoline engine.

This opens up another profitable field of study - that of the ignition velocities of gasoline and all other economically utilizable fuels over a wide range of temperatures from those encountered at the beginning of compression to the temperatures at the end of compression. Nusselt believes the effect of initial temperature is very great.

The lecturer finally considered the question of weight of the aviation engine which must always be more important than the fuel problem.

$$\frac{G}{N} = \left(\frac{P_{max}}{P_m} \cdot \frac{\frac{d}{s}}{V_m}\right) + A \quad \ldots\ldots\ldots\ldots \quad (4)$$

Equation 4 expresses the engine weight per horsepower when the engine is considered as an integration of mechanical energy from several units, and as a transmitter of energy from the several combustion chambers through the piston, connecting rod linkages

to the shaft, and thence to the propeller, on which the forces p act at different points. The power N of the engine depends upon (1) the mean value P_m of the forces applied to the pistons and (2) the relative velocity V_m between the moving and stationary parts of the energy conduit. The product $P_m \cdot V_m = N$ remains constant (apart from losses due to friction) in all the cross sections of the energy conduit. The structural material used, and consequently, the weight G is, on the other hand, essentially determined in every section of the energy conduit by (1) the maximum forces P_{max}, (2) the admitted strain s and (3) the specific gravity d of the working material. A is a supplement for the fuel conduits, the valve gear, and other accessories.

The principal determinations for the value G/N are the following: (1) the absolute length (1) of the energy conduit; (2) the permissible value s of the structural material; (3) the permissible maximum values for V_m, and (4) the value $\frac{P_{max}}{P_m}$. The value of $\frac{P_{max}}{P_m}$ for the piston, valve gear and the cylinder is equal to the value of $\frac{P_{max}}{P_m}$ for the entire engine, and in the case of the cylinder and piston, the ratio of the maximum pressure P_{max} to the mean pressure due to inertia of the masses must be taken into account. The following deduction may be drawn from equation (4). Should P_m be less than normal, in consequence of a low cylinder charge or the heating of the intake mixture to a high temperature, P_{max} will be lower in proportion, so that the ratio $\frac{P_{max}}{P_m}$ remains unchanged. The engine with re-

duced volumetric efficiency will not of necessity be heavier as it can be built considerably lighter because the quotient $\frac{P_{max}}{P_m}$ alone is decisive. When the compression ratio is low, this quotient is generally lower, so that air-cooled rotary engines turn out very well with regard to their H.P. load, in spite of their unfavorable volumetric efficiency and their low compression ratio. (This is certainly also due to the short length of the energy conduit "l" and to the lightness of the accessories A.) This relation shows that aviation engines can be perfectly well built with low weights per H.P. when using prepared fuel mixtures, in spite of the fact that they take in hot air or have extremely hot walls in order to obtain adequate vaporization, or they work with low pressures during the suction stroke in order to obtain adequate atomization.

The combustion type of engine therefore should not be chosen for aviation, or light automobile engine designed for the use of fuels of high boiling point. The latter will always be more difficult to construct on account of its high value of $\frac{P_{max}}{P_m}$ (without taking the heavy accessories into consideration). The aviation engine should rather be selected from the ignition engine class with the best possible atomization and comparatively low compression ratio. With this end in view, a systematic investigation should be made of all the important characteristics of fuels, so that the heavy-oil aviation ignition engine may attain the unusual record values which now distinguish the best light-oil ignition engines from all other combustion engines, namely:

Gasoline consumption	180 to 190 grams, 0.40-0.42 lbs. per H.P. hr.
Mean useful pressure	9 to 10 kg/cm^2, 128 to 142 lbs. per sq.in.
Load per H.P.	Only 0.8 to 1.5 kg., 1.8 to 3.3 lbs. per H.P.

NOTE I.

The surface tension of the fuel is probably of much greater importance than its viscosity in affecting atomization.

NOTE II

This is not true should the temperature of the gasoline decrease as the air temperature decreases with increasing altitude. It is probably true, should the temperature of the gasoline in tanks and fuel lines remain the same in flight as on the ground.

NOTE III.

This assumes no heating of the carburetor or manifold.

NOTE IV.

Cooling of the entire weight of air necessary for one pound of hexane 30°C would supply about 193 B.t.u.; whereas, only about 143 B.t.u. are required.

NOTE V.

It is very doubtful that hexane is the principal component of any of the present commercial gasolines, except possibly, aviation gasolines.

NOTE VI.

If the values given are for the chemical combining mixture ratio of 15.2 to 1, the manifold pressure assumed is 731 mm. of mercury. Should the manifold pressure be assumed as760 mm. of mercury, the mixture ratio will be 15.7 to 1.

NOTE VII.

The mixture ratios for the saturation values of the fuels given in Figure 4, as computed from published data, are as given below:

	Mixture Ratio	Manifold Pressure mm. of Mercury.
Naphthaline $C_{10}H_8$	12.5	760
	12.9*	785
Decane $C_{10}H_{22}$	15.7	760
	15.0*	738
Ethyl Alcohol C_2H_5OH	8.8	760
	9.0*	774
Benzol C_6H_6	15.0	760
	13.2*	669
Hexane C_6H_{14}	15.7	760
	15.2*	730

* Chemical combining ratios.

NOTE VIII

Were all temperatures mentioned higher than the saturation temperature of the fuel at the pressures existing, no condensation or separation could take place.

NOTE IX.

This is not altogether true, as the engine may be idled at times which precede demands for reliable engine operation, such as when coming out of a long dive and rising from the ground after an unsuccessful attempt to land.

NOTE X.

When H is in kilogram calories per cubic meter and P_m in kilograms per cm^2 the constant of proportionality is $\frac{427}{10,000}$ when H is in B.t.u. per cubic inch and P_m in pounds per square inch the constant of proportionality is, 778 x 13.

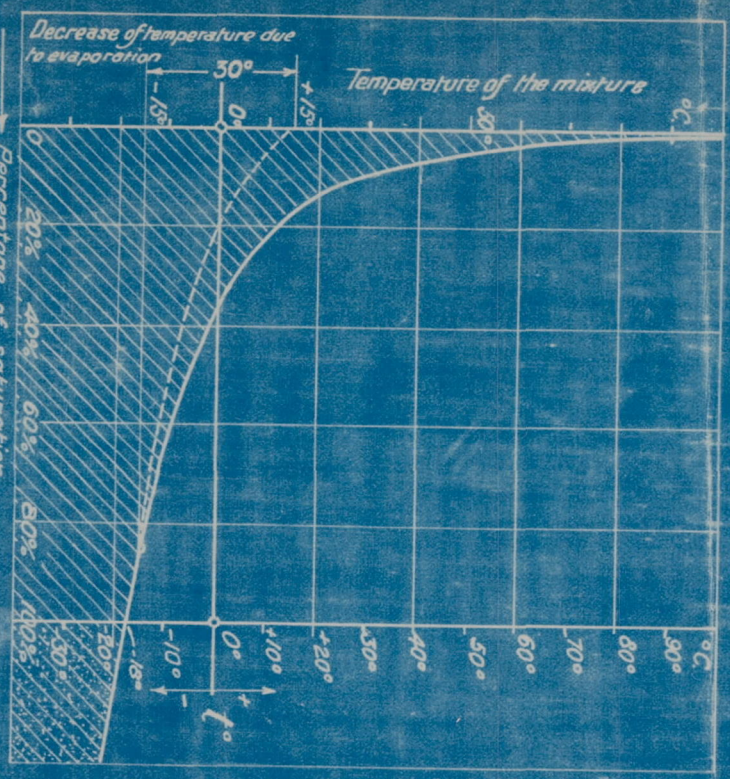

Fig. 3. Percentage of saturation of a hexane - air mixture at several temperatures.

Fig. 1. Diagram of carburetor.

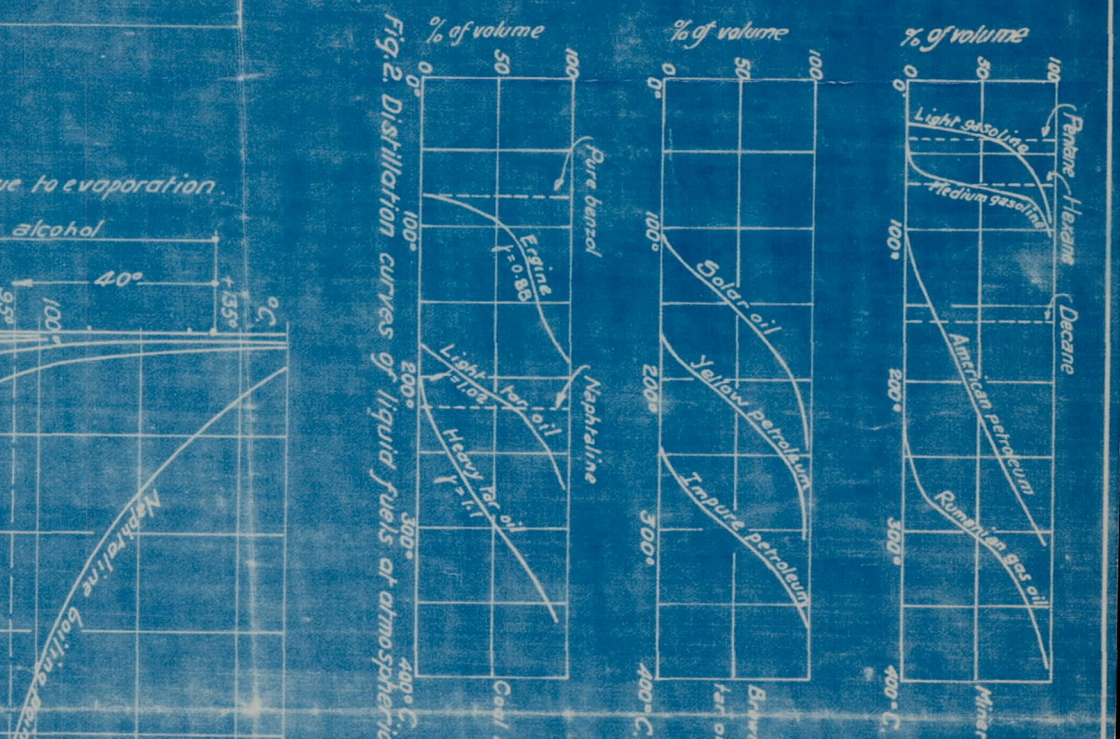

Fig. 2. Distillation curves of liquid fuels at atmospheric pressure.

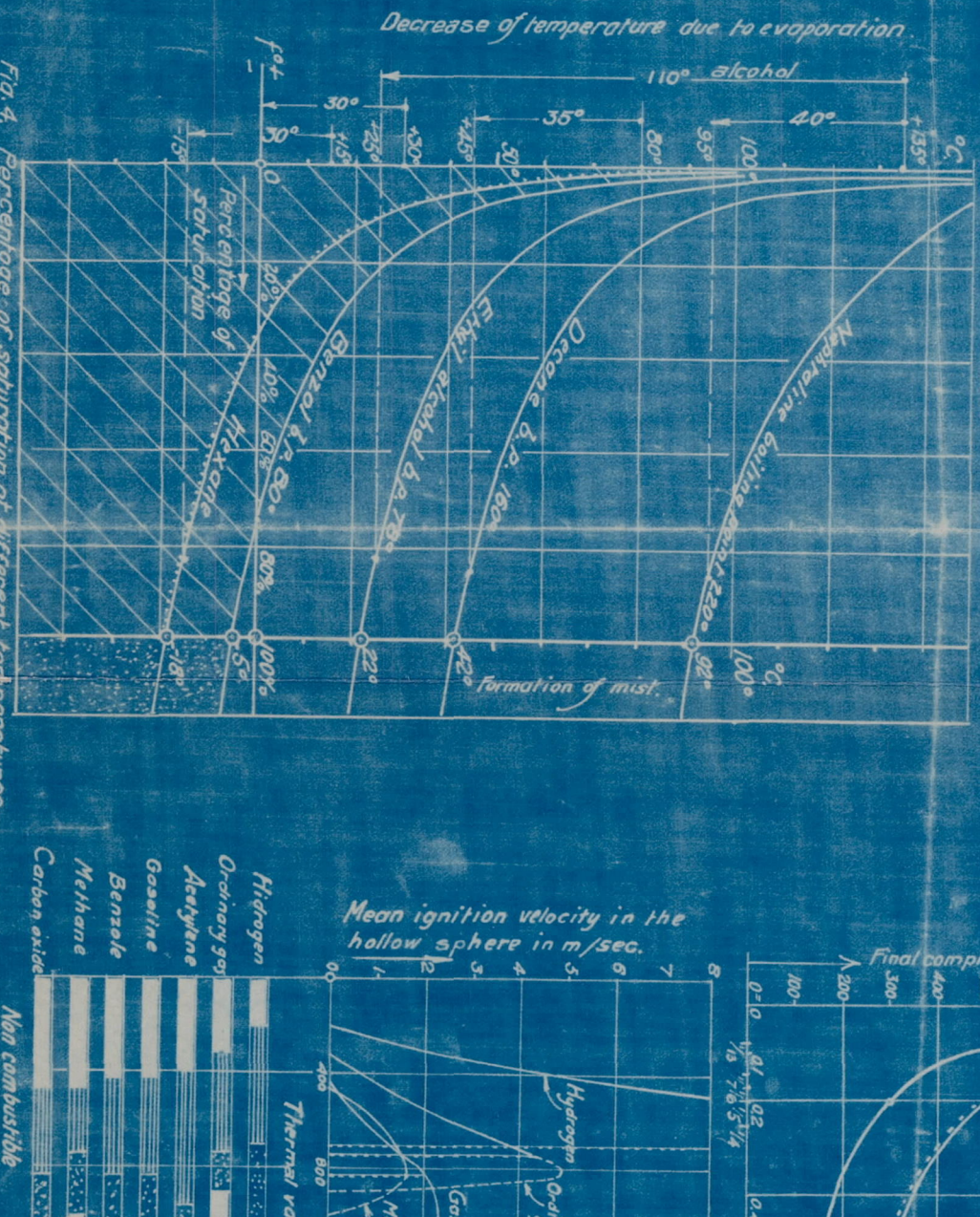

Fig. 4. Percentage of saturation at different temperatures for mixtures and several fuels.

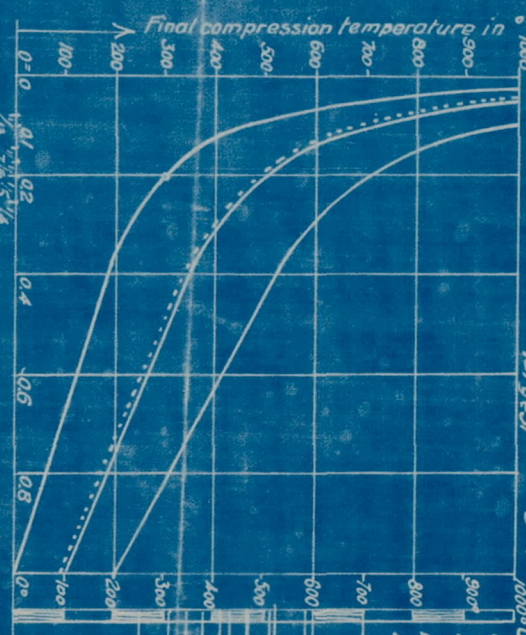

Fig. 5.

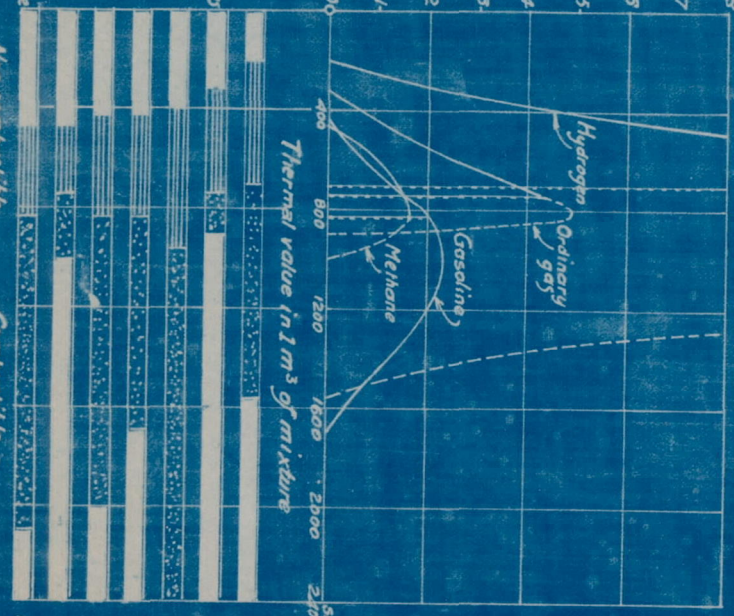

Fig. 6.

Fig. 5. Final compression temperatures with different initial temperatures and compression ratios ($n = 1.4$).
On the right side the spontaneous ignition temperatures at atmospheric pressure according to Holm are given.

Fig. 6. Ignition limits and velocities of different fuel mixtures in a closed chamber (in terms of the thermal value of the fuel in 1 m³ of mixture).

Figs. 1-2-3-4-5-6.