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# CARBURETION IN AVIATION ENGINES.

By Naval Engineer Poincaré of the S.T.Aé.

From La Technique Aéronautique, April 15, 1923.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 225.

# CARBURETION IN AVIATION ENGINES.*

By Poincaré of the S.T.Aé.

It is not my purpose to give a list and a description of all the carburetors in use on aviation engines, nor to originate a theory of carburetion. I believe, moreover, that theories can only give indications on the general nature of the phenomena and that we cannot demand quantitative results, without infinite complications. Many and complex are, indeed, the secondary phenomena grafted on the principal phenomena.

I shall endeavor, therefore, to restrict myself to a clear statement of the problem and a few of the conditions for solving it.

## I. - The Problem.

The problem is to supply the engine cylinders with a mixture of fuel and air in the right ratio to obtain the greatest power from the engine with the least consumption of fuel.

Theoretically, a certain weight of oxygen, and hence of air, is required for the consumption of a given weight of fuel and the problem is reduced to the production of a mixture of fuel and air in the correct ratio by weight."

An internal combustion engine is a machine for transforming heat energy into mechanical energy. All the heat energy possible

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*From La Technique Aéronautique, April 15, 1923, pp. 558-575.

must be obtained from the fuel by producing perfect combustion.

Consequently, all excess of fuel must be avoided, or, in other words, there must be enough air in the mixture to insure the complete combustion of all fuel it contains.

Neither must there be excess air, since, by supplying the engine with less fuel and hence fewer calories to be transformed into mechanical energy, less power is obtained, though the specific fuel consumption would remain theoretically the same.

This may be represented graphically by indicating on the abscissa the number of calories per liter of the mixture ($Q_1$) and on the ordinate the mean indicated pressure ($p_m$), reserving the symbol $p_{me}$ for the mean effective pressure.

So long as we have in the cylinder enough oxygen to burn the fuel completely, the mean pressure will increase in proportion to the number of calories per liter of the mixture. According as we consider the combustion complete with the formation of $CO_2$ and $H_2O$ (the fuels being hydrocarbons), or incomplete with the formation of $CO$ and $H_2O$, or even partial with the formation of $H_2O$ and a deposit of carbon, we will have three different outputs. The three resulting pressures will therefore be located on three straight lines, OA, OB, and OC (Fig. 1) and the slopes of these lines will accurately represent the efficiency of the transformation of heat energy into mechanical energy.

As soon as the quantity of fuel per liter of the mixture is too large for complete combustion, the quantity of heat energy transformed into mechanical energy or work is proportional to the quantity of air utilized. The latter is evidently diminished by the introduction of fuel. The curve of mean pressures, on the assumption that all the air is utilized, is therefore a straight line starting from a point D (for complete combustion) and descending gradually toward the line $O_i\ Q_1$.

For present-day engines, we may take $O_i\ D = 10.5$ at 11 kg per sq.cm. With heptane, whose heat content would be 10500 calories, it may be calculated that complete combustion corresponds to about 0.9 calorie per liter of air. The horizontal line DG will therefore cut the line $O_iA$ at the point corresponding to the content $Q_1 = 0.9$.

It follows that the line DH, giving the mean pressure for the complete utilization of the air in the mixture, will cut the line $O_i\ A$ at a point corresponding to less than 0.9 calorie per liter, or about 0.85 calorie.

The diagram giving $p_{mi}$ will consequently become (for complete combustion) $O_i\ K$ so long as the quantity of fuel is not sufficient for the complete utilization of the air in the mixture, and then KH, when the quantity of air enables the complete utilization of the fuel.

The point K gives the ratio for complete combustion without excess air or fuel. The line kK separates the regions where the mixture is too poor from those where it is too rich.

The lines EL and FJ are drawn in the same manner, in order to find the curves for the mean pressures, when the combustion is either incomplete or partial. Thus the angles $O_1LI$ and $O_1MJ$ are obtained.

Atmospheric Conditions and Coefficient of Charge.- Let us take the curve corresponding to complete combustion, $O_1KH$ (Fig. 2). In order to produce it, we assumed that the mixture was under the theoretical pressure of 760 mm Hg and at a temperature of 15°C. Otherwise, the weight of the air in a liter of the mixture would vary in the ratio of the density of the air under the actual conditions of the experiment to the density of the standard atmosphere at 760 mm Hg and 15°C. The same is true of the mean pressures and, by designating this ratio by $\mu$, we have $p'_m = \mu p_m$.

The line DKH becomes D', K', H' and $O_1K$, which defines this mixture under theoretical conditions, becomes $O_1k' = \mu O_1K$.

In practice, we must introduce another reduction coefficient, due to the fact that the mixture is never perfect. Accordingly, we write $p'_m = \lambda p_m$, so that, between the true mean pressure (under the experimental conditions $p'_m$) and the theoretical pressure $p_m$ (which we would obtain if the experiment were made with a coefficient of charge* equal to 1 and in standard air), we

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* The coefficient $\lambda$ is not what Devillers calls the coefficient of charge. He assumes, in fact, that at the instant of closing the intake valves, the air is under the atmospheric pressure (which is necessarily only approximate) and, while designating by $q$ the volume for the entire stroke, he designates by $aq$ the volume for the stroke thus reduced. This is his coefficient of charge. Our coefficient $\lambda$ is defined by $\lambda = p'_m/p_m = p'_o/p_o$, as may be easily demonstrated by considering the cycle. If $e$ is the dead space, we have $p'_o(e + q) = p_o(e + aq)$, assuming the same temperature in both cases, and, on introducing the volumetric ratio

$$\rho = \frac{e + q}{e}, \text{ we obtain } \lambda = \frac{\rho}{1 + a\,(\rho - 1)}.$$

have $p'_m = \lambda \mu p_m$, and similarly, $Q'_1 = \lambda \mu Q_i$

Theoretical Limits of the Curve.- If we assume, for the moment, that $\lambda p_u = 1$, we then have the angles $C_iKH$ and $O_iLI$ of Fig. 3. Can we really obtain such mean pressures with all the corresponding proportions of the mixture? No, a mixture of air and gasoline cannot burn in any proportions whatsoever. The gasoline content of the mixture must fall within certain limits, embracing the ratio corresponding to the chemical reaction of complete combustion. The rapidity with which the combustion takes place likewise depends on the proportions of the mixture. It is generally the greatest for a content of fuel slightly above that required for complete chemical reaction.

We now draw below $O_iQ_i$, on a certain scale, the curve giving the speeds of propagation of the combustion in terms of the number of calories contained in a liter of the mixture and of the fuel (Fig. 3).

Unfortunately, we have but little information on these curves, especially for mixtures at an initial high pressure and temperature.

For the mixing proportions with a speed of zero, the mean corresponding pressure is zero. At low speeds, the combustion does not include the whole mass during the useful phase and the mean pressure is therefore reduced by an amount corresponding to the whole mass of unused or partially used fuel. It is only at high speeds that the curve of the $p_{mi}$ coincides with the theoretical curve previously drawn.

Practical Curve.- It is found, moreover, that if we try to plot this curve by varying the adjustment of an engine so as to obtain all the degrees of richness of the mixture possible, the practical curve bends in before reaching the point K and remains below KH. By connecting it with the points N and S, corresponding to the richnesses of mixture when the speed of propagation of the combustion is zero, we obtain the curve NPRS (Fig. 3).

Practical Limits.- In practice, we cannot plot this entire curve. If the propagation speed is so low that the combustion continues while fresh gas is being admitted to the cylinders, the latter takes fire and the flame strikes back to the carburetor.

The ignition of the fresh gas may be caused by parts of the engine getting too hot from remaining too long in contact with the burning gases. This happens in the exhaust valves, if the combustion continues after they open.

If $O_1v$ is the minimum speed below which the flame strikes back, the points P and R are the practical limits of the curve.

Smoke and Carbon Deposits.- In practice, backfires occur with "poor" mixtures, but another phenomenon often interferes with working up to mixtures sufficiently rich to cause backfires also, that is, to the point R.

Before this point is reached, smoke and carbon deposits are formed, due to poor combustion. The deposits are made on the valves, pistons and spark plugs. They may cause self-ignition during the compression stroke and thus prevent the experiment from being carried farther.

On our curve, the carbon deposits may begin at the point T on the line KL or at any point above KL or below $O_1L$.

The reasoning which follows is based on the fact that the fuel is burned to the extent permitted by the amount of air in the mixture.

In considering a point X of the plane, if the whole amount of fuel corresponding to $Q_1 = O_1x$ has burned, only a portion of it could have burned completely and the rest incompletely or only partially. On drawing, through X, parallels to $O_1A$ and $O_1B$, we find that the quantity $O_1u$ has burned completely, while the quantity $O_1w$ or ux has burned partially. The sum of the mean pressures thus obtained is equal to the mean pressure obtained. In the angle $AO_1B$, we have therefore both complete and incomplete combustion, according to the air supply. The quantity of air necessary for the complete combustion of the quantity $O_1u$ of fuel is proportional to this quantity or $AO_1u$. The total amount of air utilized is therefore $AO_1u + BO_1w$. The total amount of utilizable air, however, is a linear function of $O_1x$. It is, in fact, the quantity which makes a liter with the addition of $O_1x$ of fuel. In order for the desired combustion rate to be possible, we must have

$$AO_1u + BO_1w < CO_1x + D$$

The equation giving the locus of the points at which all the air is utilized is therefore

$$AO_1u + BO_1w = CO_1x + D \qquad (1)$$

If the coordinates of the point X are

(2) $$x = O_1u + O_1w$$

(3) and $$X = O_1U + O_1W$$

by adding to these equations the proportionality equations of $O_1U$ and $O_1W$ at $O_1u$ and $O_1w$ (constant output for the same chemical reaction), we can eliminate the latter quantities and the relation in $x$ and $X$ will be linear. It is evident, moreover, that the points K and L form part of the locus, which is therefore the line KL.

Consequences of Back-firing.- In practice, the curve NPTRS comes to be almost tangent to the line $O_1A$, the back-firing limit P being, unfortunately, almost on this line.

Since, in carburetors now in use, the richness of the mixture depends on the atmospheric conditions, the point P must not be reached, excepting under certain atmospheric conditions, under penalty of seeing a carburetor, which seemed to be well adjusted one day, take fire on the next.

It is not always possible therefore to reach the point situated on the line $O_1A$, which would be the point of greatest indicated efficiency, corresponding to the minimum fuel consumption, if the mechanical efficiency were equal to unity.

Mean Effective Pressure.- In fact, this is not the case and passive resistances of all sorts prevent the mean effective pressure from being equal to the mean indicated pressure. We may put:

$$p_{mi} = p_{me} + p_r$$

Since $p_r$ is a constant, this amounts to assuming that the mechanical couple of the passive resistances is constant. This resistance would lie between 1 kg and 1.5 kg.

Whatever it may be, by taking a second origin $O_e$ such that $O_i\ O_e = p_1$, we can represent $p_{me}$ on the same graphic. The total output of the engine will then be represented by the slope of the line joining the representative point to $O_e$.

Greatest Efficiency and Greatest Power.- The point of greatest efficiency, that is, of minimum fuel consumption, is the point contact of the tangent to the curve issuing from $O_e$. It is seen on Fig. 3 that it may correspond to a slightly "poor" mixture.

On the contrary, in order to obtain the maximum power, it is necessary to have the mean maximum pressure, since we have made an abstraction of the R .P.M. which we therefore assume to be constant. The maximum in Fig. 3 shows that the point of maximum power corresponds in general to a slightly rich mixture. It coincides in no case with the point of minimum consumption, but does correspond to a richer mixture. This, moreover, is a well-known fact.

Practical Coordinates.- Since the results of experiments generally give the revolution number N, the couple $\Gamma$, and the specific fuel consumption K, it may be of interest to give the formulas which connect these quantities to those we have just considered.

$$p_m \text{ is proportional to } \Gamma$$

$$\text{and} \quad Q_1 \text{ is proportional to } \Gamma k$$

If the calculation of the specific consumption has not been made, we may start with the hourly consumption K.

$Q_1$ is then proportional to $K/N$* for any given fuel.

Utilization Curve.- In practice, aviation engines are used with a constant propeller torque, and the curves obtained by reducing the quantity of fuel with the same propeller are of special interest.

The purpose of reducing the fuel supply is to modify the coefficient $\lambda$, which characterizes the coefficient of charge. The mean pressures are reduced in the ratio $\lambda$ and the quantity $Q_1$ which characterizes the mixture must be reduced in the same ratio, in order that it may retain the same properties.

The points $d'$ must be placed after the indications of the measurements made, corrected, if necessary, by the factor $\mu$ for the exterior conditions, but not by the factor $\lambda$ which, if the carburetor is well adjusted, would superimpose all the points (or would give, if the adjustment is not perfect, a section of the curve of Fig. 3 corresponding to the various adjustments of an engine under the same conditions).

The ideal curve would be like that of Fig. 4, which almost superposes itself on the line $O_1A$, while leaving a narrow margin of safety to prevent back-firing for slight daily variations of $\mu$. We would thus have the best fuel consumption, since we are as near as possible to $O_1A$ and, on opening the throttle wide, the mixture

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* Since $q$ is the total charge in liters and $Q$ the heat content of the fuel $p_m = \frac{\pi \cdot \Gamma}{10q}$

$$Q_1 = \frac{Q}{30q} \quad \frac{K}{N} = \frac{\pi Q}{1000 + 75 \cdot + 900q} \quad \Gamma k$$

$k$ being expressed in grams per HP/hr and $K$ in kg/hr.

would become a little richer and the engine would give its greatest power.

It must be borne in mind, however, that for the conditions under which we have assumed this curve to be plotted, the richness of the mixture remained the same for all the points corresponding to the different values of $\lambda$, which are located in a straight line with the origin $O_i$.

The practical curves, which can be plotted by this method, in general only distantly approach this ideal curve. It would be desirable to keep the curve at least between $O_iA$ and $O_iB$, but this however, is not always possible.

Power Curves.- This is the second curve we are accustomed to consider. Our presentation of this runs the risk of being a little more confused. The ideal curve should, in fact, be reduced to a point, if $\lambda$ is assumed to be constant. The latter varies slightly, however, and the curves give couples whose mean pressures, in terms of the R.P.M., do not usually present very high maximums. The ideal curve would then correspond to the larger portion of the curve in Fig. 4 or, still better, to the curve (traced with dotted lines) forming the locus of the maximum of the systems of adjustment ($p_{mi}$ in terms of $Q_1$) obtained for various values of $\lambda$. Thus we would always have the maximum couple when the throttle is wide open. In Fig. 4 we have traced with dots the curves of adjustment for various values of $\lambda$.

## II. Special Requirements of Aviation Carburetors.

After thus reviewing the general conditions of the problem, it is well to consider the devices which will enable their fulfillment. I have not the space to enter into details and I will not try to describe existing carburetors, but will confine myself to a few general conditions.

The carburetors now employed on aviation engines are all derived from the one shown diagrammatically in Fig. 5, in which, under the influence of the difference of pressure between A and B (a difference due to the difference in the velocity of the air drawn in by the engine) the fuel is introduced through a calibrated spraying nozzle C. Drawn out by the current of air, the fuel is atomized and vaporized. A throttle valve D, by creating a variable obstruction and thus affecting the value of $\lambda$, regulates the gas intake.

Idling Speed and Picking-up.- Since the suction on the nozzle diminishes rapidly with the closing of the throttle, it has been found necessary to modify this design by adding a special device for idling speed. The necessity of some provision for enabling the engine to pick up has likewise led to a further complication of the diagrammatic carburetor. It is necessary to overcome the inertia of the fuel in the changes of speed. We were thus led to create a fuel reserve capable of enabling the engine to pick up, as well as to avoid stalling at low speed.

Automatism.- The necessity of automatic regulation of the fuel flow, so as to adjust the mixture of fuel and air to the varying engine speeds, has led to still greater modifications.

The engine speed may vary, either as the result of varying resistance or (the resistance remaining constant) with the operation of the throttle. Both cases may occur in aviation engines, it being very evident in the second case. It is also evident in the first case, since Mr. Rateau invented the ingenious device enabling the maintenance of a constant engine couple up to an altitude of over 5000 meters.

Must a perfect automatism be required of aviation engines? This question might possibly be disregarded, since the engine speed varies but little in engines not provided with turbo-compressors. It is always advantageous, however, to relieve the pilot of the care of adjusting the carburetion and there will always be, moreover, an increasing variation of the engine speed, as the engines acquire more reserve power.

Altimetric Correction.- Airplane designers have no objection to automatism in this sense and they are succeeding in its practical accomplishment. The problem becomes more difficult, however, when it has to do with automatic regulation of carburetion for changes in altitude.

The most elementary formulas demonstrate that the engine power varies as the ratio of the air densities $\mu$ and that the fuel consumption diminishes simply according to $\sqrt{\mu}$.

The specific fuel consumption increases therefore as $1/\sqrt{\mu}$ and the mixture gradually grows richer with increasing altitude.

Adjustment is consequently necessary and all aviation carburetors must be provided with some suitable device for making it. This device is usually controlled by the pilot, notwithstanding the great advantage of automatic control. Does this signify that the latter solution is impossible? The contrary may well be affirmed, especially since certain devices have already been invented which give at least encouraging results.

The idea which naturally comes to mind, for accomplishing such a method of control, is the employment of a barometric box. This is sensitive to variations in the density of the air, which variations must be determined in order to correct errors arising from them.

Unfortunately, its direct action necessitates a delicate instrument on account of the relatively small force available. Moreover, there is a possibility of a rupture of the box. It is interesting to imagine what kind of accident this might expose the engine to

I used the term "barometric box." It is not necessarily a vacuum box, however, It may be filled with air at the pressure $p_z$ of the "ceiling," or at the pressure $p$ on the ground, or at a still greater pressure than the latter. The difference between the pressure $p$ of the surrounding air and that of the air in the box supplies the force for operating the adjustment corrector.

If a rupture of the box occurs at a given instant, equilibrium will be established and, in the first case, the adjustment will be changed to that for $p = p_z$, that is, to the " poor" mixture corresponding to the ceiling of the aircraft. There is then a liability of back-fires with all the attendant dangers.

In the second place, the adjustment would be corrected to that for the "rich" mixture required near the ground, causing smoke, carbon deposits and even back-fires.

In order to avoid these disadvantages of the barometric box, another solution has been proposed in America. I do not know whether it has been tried. Perhaps its application may lead to unforeseen difficulties.

The adjustment corrector is kept in equilibrium by the action of a piston on one of whose faces there is exerted a pressure np, while on the other face there is exerted only the pressure p of the outside atmosphere. We then have at our disposal a force (n - 1)p, which we can make as large as we desire, since we control the value of n. The pressure np is created by means of a small pump driven by the engine, the volumetric ratio of the pump being constant.

Fig. 6 is a diagrammatic representation of this principle. In the same cylinder A, we have, on the one hand, the piston B, which controls the corrector and, on the other hand, the piston C of the pump. These pistons are separated by a partition D provided with a valve E.

The piston C uncovers, at the end of its stroke, an orifice F and when, on the return stroke, it closes F, it incloses air at the pressure p. This air, raised to the pressure np (when the piston has finished its stroke), opens the valve E, if the pressure on the B side of the partition is less than np. A few strokes of the pump give the pressure np. Since the device must also function when the pressure on the B side of the partition is greater than np, and since, in the latter case, the valve cannot work automatically, the piston C must operate the valve E at the end of its stroke, in order to enable the expansion of the confined air on the B side of the partition. At this instant, equilibrium is established in all cases between the two compartments of the cylinder A.

Piston B necessarily has leaks, but these are offset by the pump as fast as they are produced. The same holds true, even if these leaks increase as the result of wear, at least for some time. When the leaks become too great, the action of the corrector is simply rendered incomplete, instead of ceasing altogether.

Since the force (n - 1)p decreases as the leaks increase (because n diminishes) there is a tendency toward the positions of the corrector calculated for the small values of p (that is, toward "poor" mixtures, suitable for high altitudes) and it is by just keeping away from the side of the "poor" mixtures that the least margin of variation compatible with safety is obtained.

I have called attention to this device, in order to show that it may be possible to find a substitute for the barometric box, though I do not consider the employment of the latter as at all impossible. To hold such a view would be contrary to the actual facts.

At all events, it appears necessary to have an auxiliary hand control to guard against the possibility of failure of the automatic control.

Stunt Flying.- Flight conditions in banking and diving and acrobatic stunts require the modification of automatic devices, in order to make allowance for the very steep inclinations the airplane may take. The pressure at the spraying nozzle must remain constant, so that its output will not vary. It would be advantageous to place the nozzle in the middle of the mixing chamber, as is done in the carburetor of the German engine "Koerting," in which the float chamber and float have the form of a torus or ring with the diffuser and nozzle in the center. I am not informed regarding the performances of this carburetor in flight, but the device is attractive on account of its symmetry.

Output of the Nozzle.- In ordinary carburetors the main spraying nozzles have a bore of one to two millimeters. The bore is measured in hundredths of a millimeter and the diameter thus obtained constitutes the nozzle number.

With such small nozzles, the least error in the bore or the least obstruction in the fuel passage causes a relatively large variation in the output. Thus, in nozzles which have been redrilled, the results often differ from those expected. Few workshops are equipped for exact drilling and our constructors do not usually verify their nozzles with accurate gages. In fact, they measure the output under a given pressure.

In an American article I have found figures showing the variations in output with nozzles of the same number. The American tests were made on the nozzles of American and Zenith carburetors.

The latter were either principal or compensator nozzles, or principal nozzles plugged and redrilled. The output curve was plotted against the bore. For this purpose, after determining the mean output of nozzles of the same kind and number, the points thus obtained were joined (or rather a continuous curve was drawn between the points), the maximum error, with reference to this curve, varying from:

2 to 7% for the main nozzle,
1.5 to 4% for the compensator,
10 to 12% for the redrilled nozzles.

On the contrary, the maximum output of two nozzles of the same number varies from:

2 to 9% for the main nozzle,
2 to 5% for the compensators,
3 to 19% for the redrilled nozzles.

It is seen that the output varies much the most for redrilled nozzles.

It seems to be greater for the main nozzles than for compensators, due perhaps to their shape, which is quite different. The tests were made with Zenith carburetors of the old type, with a simple diffuser, before the Zenith Company made the immersed nozzle.

Effect of Vibrations.- The effect of vibrations on the output of a nozzle depends chiefly on its shape. If the calibrated portion is too long in comparison with its diameter, the output varies for both horizontal and vertical vibrations, without its being possible to give the law of its variation in terms of the vibration period.

If, on the contrary, the calibrated portion is shorter, the vibrations do not appreciably affect the output, but, if too short, the output varies in a very capricious manner. The jet does not then remain cylindrical, sometimes emerging in a sort of spiral and sometimes obliquely, without appearing to follow any law.

## III. Physical Conditions of the Problem.

Formation of the Mixture.- The mixing is done in the intake passages. The fuel leaves the nozzle in a fine spray which is carried along and vaporized in the air current. In order to enable the fuel to diffuse thoroughly, a certain length of tubing is necessary before branching to the different cylinders. If this distance is too greatly reduced, we no longer have a homogeneous mixture.

Need of Homogeneity.- The homogeneity of the mixture is an important condition. It enables us to have the same mixture in all the cylinders, a necessary condition for having the same mean pressure in them all and thus avoiding a lack of equilibrium in the engine. Even aside from the question of equilibrium, a heterogeneous mixture necessarily causes a waste of fuel, since we must adjust the carburetor so as to avoid back-fires in the "poor" cylinders.

Necessity of Vaporization.- The best way to obtain homogeneity is to assure complete vaporization of the fuel. So long as there is any mechanically conveyed fuel, there is no surety that it will not condense in the piping. Moreover, the gas is, in some sort, dried in the bends and the fuel, by reason of its inertia, tends to enrich certain cylinders at the expense of others.

Vaporization is also necessary for perfect combustion. The drops of liquid in suspension burn only on their surface, their interior becoming resinous and encrusting the engine, unless the drops are extremely small. In any event, the combustion is slowed down.

Conditions for Complete Vaporization.- In the first place, we can have complete vaporization of all the fuel only when the quantity necessary for good carburetion corresponds to a vapor tension of the fuel below the maximum tension at the temperature of the mixture. The problem is, moreover, complicated by the fact that the evaporation requires a certain number of calories. Since these calories can only be furnished by the fuel itself and by the air containing it, the temperature of the mixture is appreciably lowered during the vaporization.

Lastly, the rapidity of vaporization is not infinite, but depends on the area of the surfaces in contact (hence on the preliminary atomization of the fuel) and on the ratio of the actual tension of the fuel to the maximum tension for the actual temperature of the mixture. The rapidity decreases as the condition of saturation is approached. Since the period of time available for vaporization is very short, being at most, the intake phase followed by the compression phase up to the instant of ignition, we can understand the importance attached to the rapidity of vaporization.

It is, moreover, desirable for the vaporization to be completed before the gas stream branches to the different cylinders. Such is surely not now the case, but the vaporization is more complete and the mixture more homogeneous in proportion to the fineness of the drops of fuel remaining in suspension.

Initial Temperature of the Air.- The fall in temperature produced by vaporization is easily calculated in terms of the heat of vaporization and of the proportions of the mixture, being from 25° to 30°C for gasoline and air. It is much higher for certain other fuels, being 110°C for alcohol.

In order to obtain a total vaporization of the requisite quantity of fuel and not exceed 80 to 85% saturation, the air must be admitted at about 15°C for gasoline or 135°C for alcohol.

For each fuel it is possible to plot, in terms of the temperature, the curve giving the degree of saturation obtained for the total vaporization of the quantity of fuel required for good carburetion. These curves have the appearance of those shown in Fig. 7 for gasoline and alcohol.

On starting with air not containing gasoline vapor at 15°C, the curve giving, at various instants, the degree of saturation and the temperature of the mixture approaches the dotted curve.

By reason of the presence of water vapor in the air admitted to the carburetor, it is necessary to avoid letting the temperature of the mixture fall below 0°C, so as to prevent the formation of ice. We will return to this point later.

The initial temperature of the air should, therefore, be 25 - 30°C, which shows the necessity of heating.

Heating.- This must be effected in such a way as to furnish the mixture, at each instant, the calories absorbed by vaporization and keep the temperature of the mixture slightly above 0°C. With a cool, and consequently dense, mixture, we would have good power. Too great heating, in fact, causes a loss of power, due to the diminution of the density of the air admitted. Unfortunately, with the means at present available, it is not always possible to accomplish the heating in the best way. As a matter of convenience, in fact, the pipes conveying the mixture from the carburetor are heated, without heating the air admitted to the carburetor nor the carburetor itself. Experience has shown that this method is faulty and an endeavor has been made to improve it by causing the air, before entering the carburetor, to come in contact with the warm portions of the engine and even by heating the carburetor itself.

In fact, the temperature fall of the air between its intake and its exit from the diffuser may be quite large. Recent measurements gave 17°C. This figure applies to a particular carburetor, but may, nevertheless, serve as an indication of the probable fall with other similar carburetors. Such a fall is sufficient in winter to cause trouble in the carburetion by the condensation of water vapor from the air and even the formation of ice.

The heating is more difficult on large engines than on small ones, because the quantity of air is proportional to the square of the diameter of the pipes through which it passes, while the cooling surface is only proportional to the diameter. It may be objected that the length of the pipes is likewise considerable, but (at equal gas velocity) the vaporization of the fuel should take place in the same period of time and consequently in the same length of pipe.

Consequences of Cooling.- The heating is a difficult matter, but especially important, because cooling produces disturbing effects at all points where condensation is possible, whatever may be the relative length of the passage traversed by the gases.

The incrustations of ice, which form at the points where the vaporization is most intense, may either diminish the air flow, and thus enrich the mixture, by forming on the diffusers, or diminish the fuel flow, and thus make the mixture poorer, by forming on the fuel exits. Ice forming on the throttle valves may prevent their operation by the pilot.

Cooling may also produce other less-known results. If the atomization of the fuel is poor, the evaporation from the surface of the drops may result in the freezing of the fuel itself. Misfires may thus be produced in the engine, the mixture being considerably impoverished. The frozen particles of fuel may even be projected into the exhaust where they burn perfectly.

Heating the Fuel.- This depends on the nature of the fuel. It must be kept at the temperature where its viscosity will not interfere with its flow, but it is absolutely necessary to avoid the formation of any fuel vapor before reaching the spraying nozzle.

It must, in fact, be borne in mind that the nozzle has been adjusted for a fuel of given density and, though the density varies but little, for a liquid, in terms of exterior pressure and temperature; it will vary exceedingly, if the nozzles emit a mixture of liquid and vapor. If the preliminary vaporization of the fuel were necessary, it would have to be complete and would necessitate some kind of gas carburetor.

Fuels.- In fact, liquid fuel is always employed, in the present state of the problem of carburetion on aviation engines.

It is the ideal fuel, in consideration of the great importance of the weight carried and its large heat content, while requiring only a light container. It is, in some sort, the number of calories carried, not simply per kilogram of the fuel itself but per kilogram of fuel plus container. The questions of bulk and cost both evidently play their part.

The kindling point is also important, on account of the ever-present danger of fire, as likewise facility of storing and replenishing.

Volumetric Compression.- For any given fuel there is a certain volumetric compression which must not be exceeded, either by reason of spontaneous ignition, which may occur during compression or because of detonation.

Since the thermal efficiency is a function of this volumetric relation, one fuel may be better than another or just as good, if it renders possible a higher compression, even with a smaller heat content.

Thus, at equal compression (4.7), for a specific consumption of 244 grams of gasoline per HP, we have a consumption of 535 grams of alcohol. If, on the contrary, the compression in the alcohol engine is carried to 7.4, the consumption per HP immediately drops to 408 g.

The advantage obtained by increasing the compression soon diminishes. In order to demonstrate this, it is only necessary to plot the curve of thermal efficiency and that of its inverse multiplied by a certain factor which gives the theoretical consumptions.

We thus obtain the following figures, $\rho$ being the volumetric ratio, $\mu$ the thermal efficiency and $k$ the theoretical consumption per HP. Column $\Delta k$ gives the variations in consumption which may be expected from increasing the compression by unity.

| $\rho$ | $\mu$ | $k$ | $\Delta k$ |
|---|---|---|---|
| 3.5 | 0.313 | | |
| 4.0 | 0.340 | 177 | |
| 4.5 | 0.363 | | 20 |
| 5.0 | 0.383 | 157 | |
| 5.5 | 0.409 | | 12 |
| 6.0 | 0.416 | 145 | |
| 6.5 | 0.429 | | 8 |
| 7.0 | 0.442 | 137 | |
| 7.5 | 0.454 | | 7 |
| 8.0 | 0.464 | 130 | |

The engines now in use are designed for a certain compression. This compression may be increased by changing the pistons, but care must be exercised not to subject the engine to explosion stresses which it is not designed to withstand, as there is danger of tearing off the cylinders. I have myself seen twice, under different but similar circumstances, a whole group of cylinders torn off as the result of a rupture of the crankcase.

Fuel Mixtures.- An endeavor is being made to find a substitute for gasoline or to diminish the consumption of the latter by mixing it with other substances:

1. By taking some substances, like alcohol, with a smaller calorific content and endeavoring to obtain a suitable consumption per HP by increasing the compression and by adding other substances to increase the calorific content of the mixture;

2. By mixing other substances with gasoline, or any other similar hydrocarbon of high calorific content, and utilizing the mixture under greater compression.

Hitherto, we have taken gasoline, which is itself a mixture, and endeavored to refine it so as to reduce it, as nearly as possible, to a simple substance with a definite boiling point or temperature of distillation, this being recognized as a condition for good carburetion. A mixture is then made by starting with the refined gasoline. Even thus the desired result is not always obtained and it is very liable to happen that, due to poorer combustion, the consumption per HP is not proportional to the calorific content of the mixture.

With carefully selected mixtures, however, an appreciable gain may be effected. Thus, for example, without changing the volumetric compression, the specific consumption of a mixture of alcohol and gasoline can be reduced to 285 grams, while that of alcohol alone is 400 grams.

Danger of Separation and Congelation.- Before employing mixtures, however, it is necessary to make sure of their stability under the influence of outside agencies. In some mixtures, separation is effected by low temparatures, while in others even the humidity of the air is sufficient to cause separation.

The dangers from separation are serious enough to warrant precautions. In fact, if the carburetor is adjusted for a "poor" mixture, we are exposed to almost certain back-fires in using the heaviest constituent alone. The heaviest constituent sinks to the bottom of the tank and alone passes to the carburetor after the separation.

There is also danger that one of the constituents may congeal under the influence of the cold and the crystals may produce similar results by obstructing the fuel pipes. Such mixtures should not be used, therefore, without first being assured that there is no danger of troubles of this kind.

Lastly, it is necessary to make sure that the substances thus introduced into the fuel have no harmful effect (by oxidation or otherwise) on the tubing, carburetor or valves.

The problem of carburetion is therefore a complex one and, in order to solve it, all branches of science must be enlisted. It is at the same time, a problem of mechanics, of thermo-dynamics, of physics and of chemistry. It is also an economic problem, since we must know where to find the fuel and how to obtain a supply. For the sake of completeness, we might perhaps add the psychological factor, since it is necessary, especially in aviation, for the carburetor to inspire confidence in the person employing it.

Translated by National Advisory Committee for Aeronautics.

Figs.1. & 2.

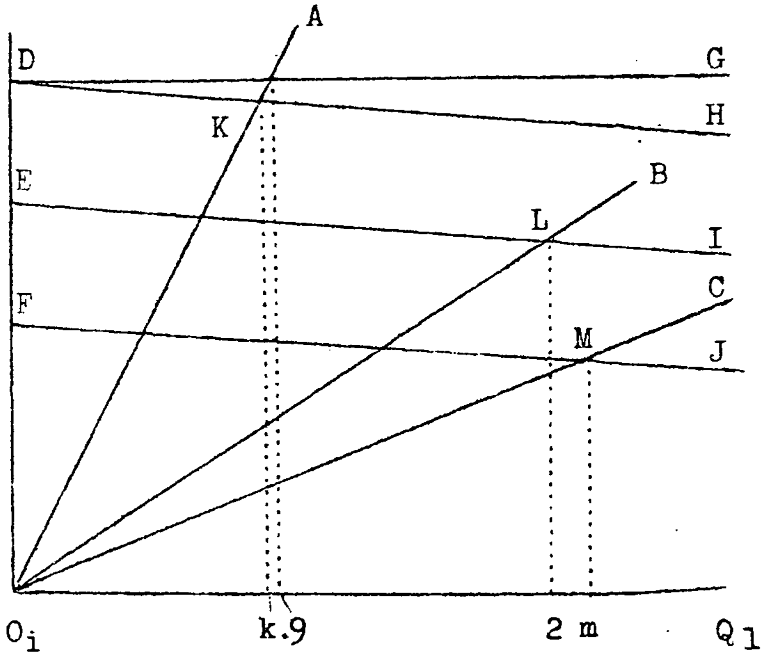

Fig. 1

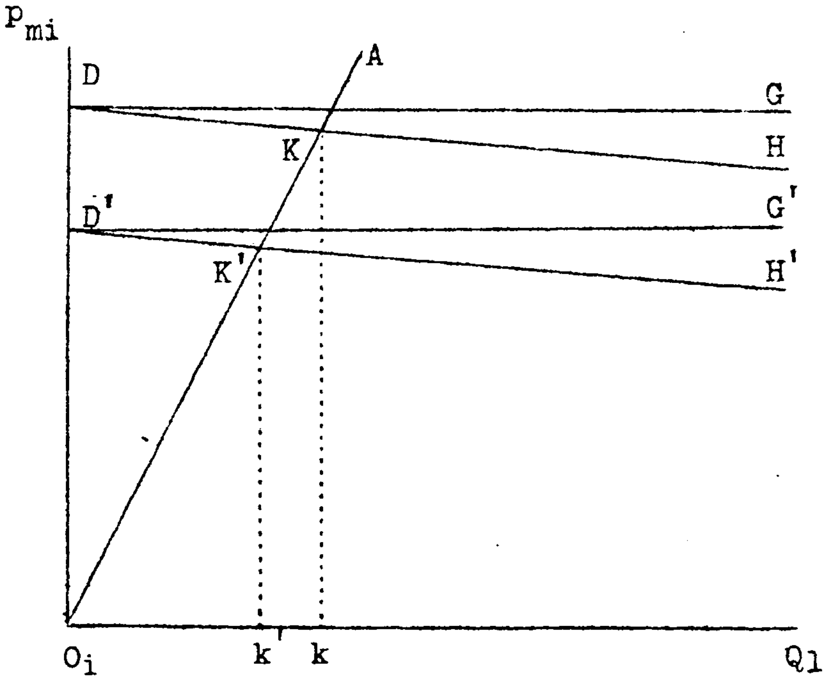

Fig. 2

Fig.3.

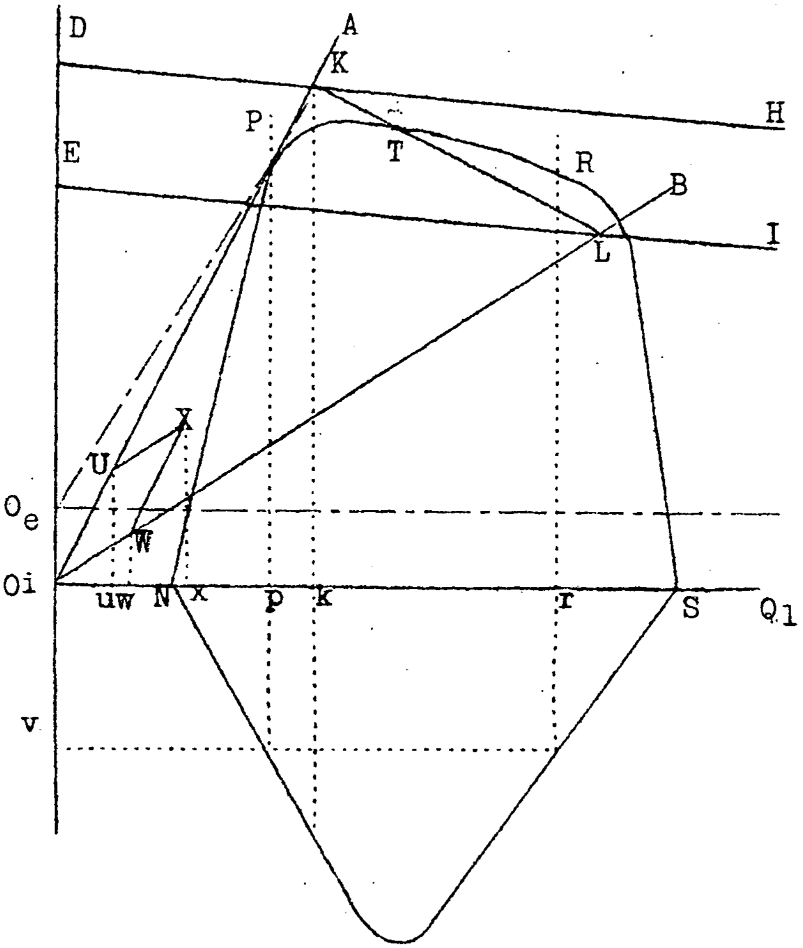

Fig. 3

Figs.4,5,&6.

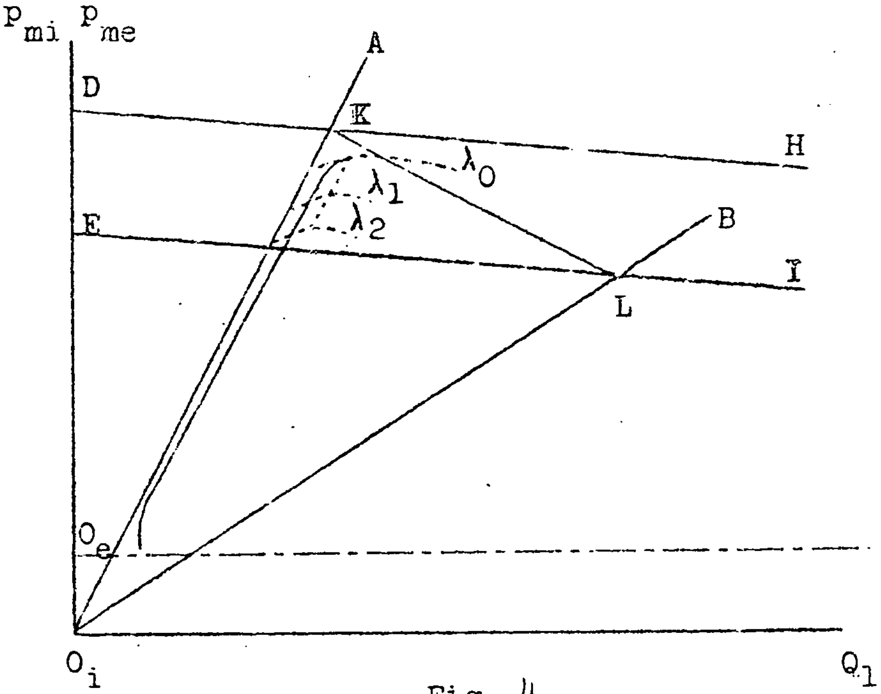

Fig. 4

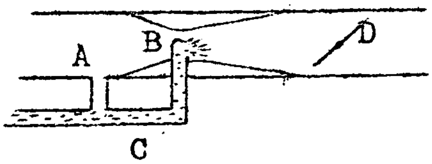

Fig. 5

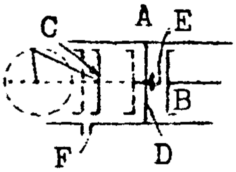

Fig. 6

Fig.7

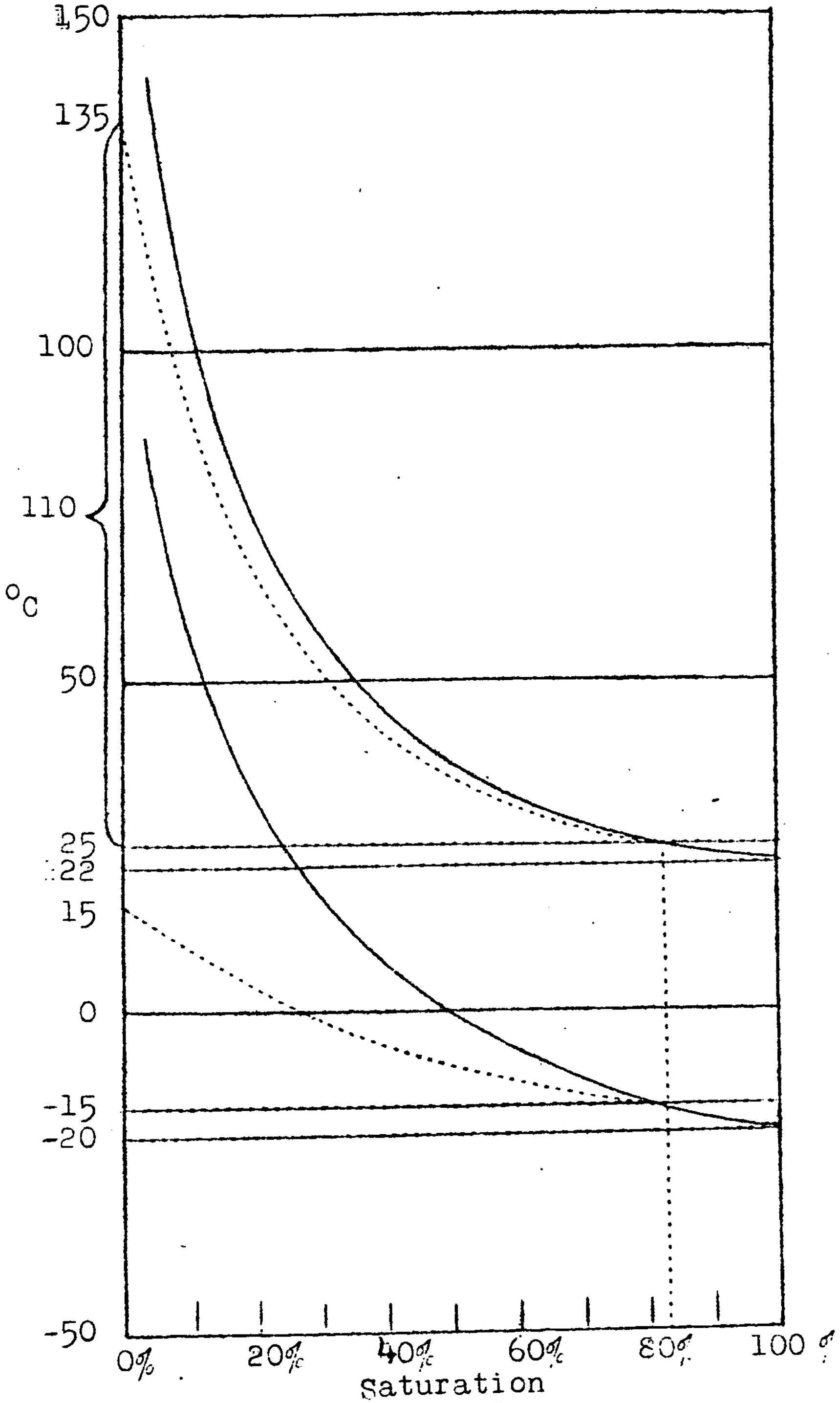
150
135
100
110
°C
50
25
22
15
0
-15
-20
-50
0%
20%
40%
60%
80%
100 %
Saturation

Fig.7