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EXPERIMENTS WITH GM 1

Report letter No. 953/1

Experiments with GM 1 on the DB 601 F engine.

1. Formula Index.

Symbol	Dimension	Significance
N_e	H.P.	Output with GM 1
N_{eo}	H.P.	Output without GM 1
n	r.p.m.	Engine speed
G^x	g/sec	Addition of GM 1 in unit time
λ		Excess air ratio.

2. Scope and purpose of the experiments.

Power and consumption measurements were made for the DB 601 F at heights above the full throttle altitude with the addition of GM 1. The amounts of GM 1 injected in unit time, G^x, were varied between the limits 0 and 120 gm/sec, at heights of 8, 10, 12 km by employing nozzles of internal diameters 1.5, 1.8, 2.0, 2.5 and 3.0 mm. Injection took place immediately before the blower. The injection pump control was used for the delivery of the fuel without any external changes.

It was the purpose of the experiment to determine the specific output $\Delta N/G^x$ obtainable for each g/sec GM 1 addition, as a function of the amount of GM 1 injected and of the height. Further it was desired to ascertain the specific fuel consumptions resulting and the ratio of oxygen to fuel during the experiment.

3. Experimental methods.

The DB 601 F engine was mounted on the test stand in the manner generally employed for altitude experiments. During the experiments the GM 1 was taken from a bottle containing about 28 kg under a pressure of from 30 to 33 kg/cm^2. The consumption was determined by weighing. For each measurement a steady state, in which temperature and fuel control were constant, was reached after 1 to 2 minutes. All measurements were taken at 2500 revs/min. and with open throttle. Corresponding to each GM 1 measuring point determined by size of the nozzle and the height one point without GM 1 was measured at the same r.p.m..

4. The results.

The observed outputs N_e are plotted against the amounts of GM 1 for various heights in fig. 1; fig. 2 gives the increases in the output calculated therefrom, $\Delta N_e = N_e - N_{eo}$, fig. 3 finally shows the specific output $\Delta N_e/G^x$ referred to the GM 1 addition. It appears that the specific output for small amounts of GM1 is of the order of 3 H.P. sec/g which agrees with that measured elsewhere. The value decreases with increasing amounts of GM 1, to an extent increasing with altitude.

Two factors are responsible for the decrease. First, the air content of the cylinder charge increases slightly during operation with GM 1 on account of the larger pressure rise in the blower (higher density of the supply); this gives rise to a further, if smaller, increase in output, beyond that due to the utilisation of GM 1. The effect however, decreases as the amount of GM 1 increases; the corresponding output gain must therefore fall. This will be dealt with more fully in a later paper.

To a much greater extent the decline in the specific output is determined by the fuel metering through the regulator. The latter reacts to boost pressure, boost air temperature and exhaust back pressure and according to these factors it adjusts the amount of fuel when air is the working medium. The regulator is incapable of meeting the enhanced oxygen content of the GM 1 part of the charge; weakening of the mixture therefore follows addition of GM 1. The phenomonon gets more important at greater heights. This state of affairs is shown by fig. 4; it is again represented in fig. 5, against the excess oxygen ratio λ.

The falling off of the specific output which is seen in fig.3 is thus mainly due to loss of power caused by lack of fuel. It can probably be partly compensated for by enrichment. This will be elucidated by further experiments in which the fuels are fed in by hand.

Fig. 1 - Effective power N_e for various amounts of injected GM 1 and at various altitudes. Supply of fuel by regulator
$n = 2500$ revs/min
Ordinate: effective power N_e

Fig. 2 - Output increase ΔN for various amounts of injected GM 1 and at various altitudes. Supply of fuel by regulator $n = 2500$ revs/min.
Ordinate: Output gain.

Fig. 3 - Output gain $\Delta N/G^x$ for various amounts of injected GM 1 and at various altitudes. Supply of fuel by regulator.
$n = 2500$ revs/min
Ordinate: Specific output.

Fig. 4 - Specific fuel consumption for various amounts of injected GM 1 and at various altitudes. Supply of fuel by regulator.
$n = 2500$ revs/min.
Ordinate: Specific fuel consumption

Fig. 5 - Oxygen excess number λ for various amounts of GM 1 injected and at various altitudes. Supply of fuel by regulator.
$n = 2500$ revs/min.
Ordinate: Excess oxygen ratio λ.

Increasing the output by the addition of GM 1 to the aero-engine cylinder charge and the effect of engine and operating conditions.

Tests so far gave different results for the output increase with GM 1 according to the engine used, the method of introducing GM 1 and the operating conditions. The causes of these differences are investigated below:

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1. The influence of the amount of GM 1 on the proportion of air in the charge and on the specific output.

If GM 1 is introduced into the intake pipe of an internal combustion engine, more work per unit weight may be made available from this part of the charge in the presence of sufficient fuel, compared with air. This extra work is determined by the larger proportion of oxygen, viz. 36.4 per cent by weight and by the heat of decomposition of 400 kcal/kg. Air with 23.3 per cent of oxygen gives about 700 kcal/kg for an ordinary fuel, Gm 1 however liberates

$$700 \times \frac{36.4}{23.3} + 400 = 1492 \text{ kcal/kg}$$

Apart from this direct contribution to the engine output by adding GM1, the output is also affected by the proportion of air in the charge. Let us first consider the latter effect under the assumption of fuel sufficient for the output to be dependent on air and GM 1 charge only. Further let us always compare operational points at equal altitudes and the same engine speeds. In particular let the operational state without GM 1 be the standard for expressing the output increase Δ Ne.

The influence of the GM 1 addition on the proportion of air in the charge may be analysed into several parts.

a) The GM 1 evaporates when blown into the boost air. It withdraws from the boost air the heat of vaporisation required for the process ($r = 45$ kcal/kg) and thus cools the boost air. This entails an increase in the boost air density and thus increases the amount of air in the charge.

b) If the GM 1 is introduced before the blower, then the cooling causes an increase in the blower pressure ratio, the density and the weight of boost air.

c) The GM 1 introduced displaces a corresponding weight of air from the cubic capacity available. The molecular weight of GM 1 is 52 per cent higher than that of air; its partial pressure in the same volume and at the same temperature is therefore 52 per cent smaller than that of the same weight of air. A certain weight of GM 1 therefore only displaces $\frac{1}{1.52}$ = 0.658 of its own weight.

d) A further loss of charge is caused by the increased effect of the wall and the residual gas in the cylinder when GM 1 is used. It has been shown by experiments which are described below that the temperatures of the residual gas and of the wall increase as the amount of GM 1 added becomes greater. Since the temperature of the fresh gas falls at the same time, the heating up on entry into the cylinder becomes larger. The density and weight of the charge therefore become smaller.

According to the above there is a definite connection between the proportion by weight of air in the charge and the amount of GM 1 added for a given engine and at any one operational point fixed by the altitude and the number of revolutions. This relation is linear as far as concerns a) and c). An the same is nearly true for b). The function indicated by d) cannot be predicted by mere inspection.

In order to elucidate this state of affairs, experiments measuring power, weight of air, boost air temperature and pressure at 10 km altitude, at 2500 revs/min. and with fully open throttle were carried out on DB 601 F and DB 601 Q engines for various additions of GM 1 per unit time. The injection of the GM 1 was carried out before the blower, with calibrated nozzles of diameters 1.5, 2.0 and 2.5 mm. The results obtained are shown in fig. 1. The plot of both the boost air temperatures t_{vV}, measured in the pressure line immediately in front of the valves, and of the boost pressure, against the amount of GM 1, G^x g/sec, are linear. The weights of air consumed G_L, on the other hand, at first rise under the conditions already described and fall off again when larger amounts of GM 1 are used. On the whole the addition of GM 1 increases the proportion of air in the charge as compared to the comparison point without GM 1. The result is thus that the output is raised more than corresponds to the direct increase due to the addition of GM 1. The course of the air weight curve should be repeated in the output curve; this influence is however so small, that the output curves are nearly straight lines.

One can see that one can attain linear output increases by raising the amount of GM 1 addition. The GM 1 amount related to the increase of output, the so-called specific output Δ Ne/G^x H.P.g/sec is thus constant over the whole range. In the present case it has the value 2.94 H.P. gm/sec for the F engine, 3.67 H.P. gm/sec for the Q engine. This large difference will be discussed below.

2. The influence of altitude on the specific output.

For constant GM 1 addition the air - GM 1 ratio is displaced in the direction of the GM 1 with increasing altitude and consequently decreasing weights of air intake. The cooling by evaporation of the GM 1 thus becomes more important as the altitude increases. Similarly for the change in the blower pressure ratio due to the GM 1 addition. As however the pressure in front of the blower decreases at greater heights, one does not expect the absolute gain in the boost pressure to change much with altitude. The absolute increase in output and thus also the absolute boost pressure increase are the decisive factors for specific output; a change in specific output with height is therefore not to be expected. The output curves at altitudes of 8, 10 and 12 km are plotted in fig. 2. They show the same gradients to a close approximation, the values obtained for the specific output being 3.0, 2.94 and 3.0 H.P. gm/sec.

3. The influence of the properties of the engine on the specific output.

The large difference in the specific output for the two engines

DB 601 F and Q, which had already been mentioned and may be clearly seen from fig. 1 is due to the peculiarities of the engines. The F engine has a larger valve overlap, viz. 106° crank angle as compared with 96° crank angle for the Q engine. The former also has a lower compression ratio, viz. $\mathcal{E} = 7.3$ as compared with $\mathcal{E} = 8.4$ for the Q engine. Both these properties of the F engine cause a greater air consumption; this is confirmed by the observed values of fig. 1. We are then faced with the same phenomenon that was mentioned in the consideration of the effect of altitude. In the Q engine with its smaller air weight, the addition of the same amount of GM 1 before the blower produces a much greater falling off of the temperature of the aspirated charge (compare fig. 1). In consequence of this larger temperature drop and boost pressure rise, the increase in output seen in fig. 1 is much steeper; it corresponds to a yield of 3.67 H.P. sec/gm as compared with 2.94 H.P. sec/gm for the F engine.

One can calculate the temperatures and boost pressure ratio on the basis of the observed values of air and GM 1; a fairly good approximation to the measured values is obtained. Part of the increase in the output yield for the Q engine is also explained by the higher efficiency due to higher compression. It permits a more favourable exploitation of the GM 1 part of the charge. Another factor favourable for the Q engine is the smaller loss of GM 1 due to scavenging. These two factors however are of minor importance.

The particular type of the blower and of its field of action also have some influence on the output yield because the alteration in the charge resulting from the addition of GM1 causes a displacement of the operational point.

It may be assumed that a larger specific output might be obtained for the F engine if the valve timing were altered so as to diminish the scavenging; this is because the gain through increased scavenging is probably less than the other effect described.

4. GM 1 Injection behind blower.

When the GM 1 is injected behind the blower, the raising of the boost pressure ratio, mentioned under b) above and due to the cooling of the charge, will not be secured.

To determine the consequent loss in specific output the curves plotted in fig. 1 for injection in front of the blower for the two engines DB 601 F and Q were repeated for injection behind the blower. In this case the GM 1 nozzle was inserted at the intake elbow, between the throttle and the branching of the intake pipe. The results are shown in fig. 3.

The weight of air now falls steadily; on account of this the specific output can no longer reach the high value which it had when the injection took place in front of the blower. The values are 2.55 H.P. sec/gm for the F engine and 2.87 H.P. sec/gm for the Q engine. The superiority of the Q engine is again shown clearly, the causes being the same as they were for injection before the blower.

The fall in temperature of the boost air in front of the valves is steeper than that of the corresponding lines in fig. 1. Part of the cooling effect is compensated for by the adiabatic heating which increases as the boost pressure ratio rises. A displacement of the GM 1-air ratio in favour of GM 1 is also brought about by the decreasing amount of air for injection behind the blower; it entails greater cooling for injection behind the blower. This decrease in the amount of air further leads to a falling off of the supercharger drive power and to a displacement of the operational point of the blower along the r.p.m. line, which is the cause of the small increase of the boost pressure which may be seen in fig. 3. On the one hand we have the favourable effects of injection behind the blower which have been enumerated above; on the other hand the output loss relative to injection in front of the blower is considerable; this is shown by a table of the "observed" values of the output yield.

Type of engine	Output yield for GM 1 injection in front of blower	behind blower
DB 601 F	2.94	2.55 HP.s/g
DB 601 Q	3.67	2.87 "

5. Summary.

The increase in output that can be obtained by the addition of GM 1 is experimentally investigated as a function of the amount of GM 1, the altitude, the properties of the engine and the place of injection, before or after the blower. It emerged that within the range investigated the output yield is practically independent of the amount of GM 1 added in unit time up to about 120 gm/sec as long as the supply of fuel is sufficient. The altitude also has no observable effect on the output yield.

The two types of engine used for the investigation DB 601 F and DB 601 Q showed widely different values for the output yield at the same operational point, defined by altitude and the number of revolutions. The main cause of this is to be sought in the difference in the air consumption of the two engines at one operational point; this in turn is due to the difference in the valve timing and in the compression of the two engines.

Changing the point at which GM 1 is injected to behind the blower results in a considerable fall of the output yield compared with injection in front of the blower.

Fig. 1 - The engine characterestics as a function of the addition of GM 1. Introduction of GM 1, before blower, engine 601 F and Q, height 10 km., n = 2500 revs/min.
Ordinates: Boost Air temperature; boost pressure; weight of air; effective power N_e.

Fig. 2 - Increase of output as a function of the height. Introduction of GM 1 before blower, engines DB 601 F; 8.10 and 12 km altitudes; n = 2500 revs/min.
Ordinate: effective power.

Fig. 3 - The engine characteristics as a function of the GM 1 addition. Introduction of GM 1 behind blower, engine DB 601 F and Q, height 10 km., n = 2500 revs/min.
Ordinates: Boost air temperature, boost pressure, weight of air, effective power.

Report letter No.953/3.

More information on the operation of aero-engines with the addition to the charge of GM 1.

This investigation concerns the influence of the addition of GM 1 to the charge on the mechanical and thermal load. Clarification is also obtained as to the influence of the ignition timing on the operating conditions of the engine when adding GM 1.

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I. The mechanical stress on the engine and the influence of ignition in GM 1 operation.

When the number of revolutions remains constant the mechanical stress on the engine depends on the pressure curve in the cylinder during the cycle, particularly the maximum pressures. The chemical properties of the GM 1 lead one to suppose that the GM 1 may have an influence on the course of the combustion and thus on the pressure curve. In order to get information as to how the engine would behave under higher loads, information which may be decisive for the applicability of the GM 1 method, the pressure curve was taken at points of equal output with and without the addition of GM 1. The pressure curve and the maximum pressure in particular depend on the time of ignition; the influence of the latter was therefore also investigated.

The DB 601 F was run with various ignition timing at an altitude of 10 km., with the throttle fully open, with injection of equal amounts of about 105 gm/sec GM 1 before the blower. The mixture was adjusted by hand to give the highest output. After this curve, a comparative curve was run without GM 1 in such a way that the optimum points of the curves gave equal outputs (N_e).

The equality in output was obtained by increasing the air pressure before the engine and thus the boost pressure in the second case. All other characteristic data were kept to, particularly the air temperature corresponding to an altitude of 10 km. in front of the engine and the pressure behind the engine. This was done in order to have the same conditions for the two comparative runs. A third run was carried out for normal operation at an altitude of 10 km.

For all the measuring points, indicator diagrams were taken from cylinder 1 by means of a quartz chamber and an oscillograph. Several diagrams were taken for each point in order to equalize the distribution of the maximum pressure values as recorded in the diagram. The mean maximum pressure was then determined from the several diagrams.

In fig. 1 the results are plotted against the time of ignition in degrees of crank angle. Let us first consider the output curves. The times of ignition for optimal output agree for the 10 km. line and for the line run with increased output without GM 1 (45° crank angle B.T.C.); when GM 1 is added, however, the optimal ignition time is displaced forward by about 10° crank angle. This adjustment of the ignition from 45° to 35° B.T.C., when GM 1 is used, brings with it a gain in output of 30 H.P. in the present example. An alteration in the ignition control is thus demanded in order to obtain the highest output yield for the addition of GM 1 to the charge.

The adjustment of the ignition also entails a large diminution of the maximum combustion pressure and thus in the mechanical load on engine (fig. 1). In the present case the maximum pressure, with GM 1, is about 10 kg/cm² less than for the normal operational point giving the same output, if the ignition is adjusted to its optimum; if the ignition is kept the same, then, in general, the maximum pressure with GM 1 will be higher than without it.

The cause of this difference in the behaviour is probably due to the fact that the combustion with GM 1 addition is considerably faster than without it. The positions of the respective combustion peaks, measured in ° crank angle A.T.C., are compared in fig. 1, the times of ignition being the same. For operation with GM 1 the peak is always about 9° crank angle earlier, the time passed from the point of ignition is correspondingly shorter. The maximum of the pressure is thus reached at a time when the cylinder space is smaller and the pressure must rise. If, instead of points having equal times of ignition, one compares points at which the peaks of the combustion have the same position, then the maximum pressures with GM 1 are consistently lower. This is shown in fig. 2. Here the maximum pressures have been plotted against the path the piston has traversed from the top dead centre to the time of the combustion peak. This path is a measure of the cylinder volume available at that instant. The optimal output is incidentally obtained for nearly identical positions of the combustion peaks in the two cases.

Indubitably the temperatures obtaining when GM 1 is added are higher than otherwise; that the maximum pressures in the former case are nevertheless lower, when compared properly, may be explained as follows. When GM 1 is used, the weight of the charge G in the cylinder is smaller than it is at a comparison point which gives the same output; the gas constant R of the GM 1 - air mixture and that of the burnt gases is also smaller than in the case of operation with air. Applying the general gas laws to the gases contained in the volume V corresponding to the instant of the combustion peak, thus

$$p = \frac{GRT}{V}$$

one can see that the maximum pressure p during operation with GM 1 may be smaller in spite of the higher temperature T, as long as the product GR is sufficiently small. Rough calculations have indeed confirmed the result of this measurement.

Fig. 3 is an example for ignition at 35° crank angle B.T.C.: one indicator diagram is shown for each of the three runs viz. normal operation, operation with 105 gm/sec of GM 1 addition and normal operation with increased output. It is distinctly shown that for operation with GM 1 the combustion peak is advanced by 10° crank angle as compared with the diagrams without GM 1.

Summarizing one may say that the maximum pressure of the combustion with GM 1 is lower than that pressure reached with normal operation if one adjusts the ignition timing. In both cases the same optimum output is obtained, the position of the combustion peak relative to the top dead centre being nearly the same but reached with a maximum pressure lower by 10 kg/cm^2 when GM 1 is added.

When the ignition is regulated, then the mechanical stress on the engine is less when GM 1 is added than for normal operational points giving the same output. Since this correction of the ignition is necessary also for adjustment to the optimum output, it seems advisable to alter the ignition timing in the prescribed sense.

II. The thermal behaviour of the aero-engine when GM 1 is added to the charge.

1. Purpose and method of the experiments.

We wanted to investigate the effect of GM 1 addition on the thermal loading of aero-engines. For this purpose operational points of the engine giving the same output were compared with and without GM 1 addition. The following characteristic data were measured: the temperature at the plug seat, the temperature of the exhaust, and the amount of heat carried away in the cooling water. The thermal condition of the engine depends to a very large extent on the fuel air ratio; the possibility of a displacement of the thermal state by changing the composition of the mixture was therefore investigated.

In order to elucidate the problems so-called consumption loops were run with the DB 601 Q engine at an altitude of 10 km. and n = 2500 revs/min. The throttle was fully open, the amount of GM 1 kept constant in each case (injection before blower) and the consumption loops i.e. plots of the output against the specific fuel consumption were taken, (figs. 4 and 5). All these loops were taken for a variety of GM 1 injection nozzles i.e. varying quantities of GM 1 injected per unit time. Again for each of these loops one run was made without GM 1, the optimum points again having been adjusted to give the same output N_e. This increased output without GM 1 was again achieved by a corresponding increase of the air pressure in front of the engine, the other characteristic data of the operational state being kept unaltered, particularly the temperature of the air in front and the pressure behind the engine. In this way the initial temperature at the GM 1 injection point in the intake was kept the same for the temperature course of the working cycle in both methods of operation. Differences in temperature could now only be due to the difference in the charges, since the output was the same in both cases and since the effect of the fuel does not come in when one compares corresponding points on the consumption loops. All the measuring points were run with the optimum ignition timing, whether GM 1 had been added or not. Difficulties were experienced in keeping constant the quantity of GM 1 per unit time over the duration of one loop. It was found to be impossible to avoid variations up to ± 4 per cent; this involved a variation in the results. The loops represented in figs. 4 and 5 were selected from a larger number; these were run at an altitude of 10 km at n = 2500 revs/min. with 80 and 94 gm/sec GM 1 respectively. They may be considered to be typical curves.

2. Output and composition of mixture.

The first thing that meets the eye is that the minimum fuel consumption is considerably less for these lines when GM 1 has been added. This is not equivalent to a better fuel efficiency. It is due to the interrelation between fuel consumption and the total output; in this relation is included the output available from the heat of decomposition of the GM 1, i.e. a part of the output not originating in the fuel.

One can calculate the difference in the energies contained in the quantity of fuel at the most economical point A and at the point B giving the same output (or points A' and B'). This difference may be equated to the heat of decomposition of the quantity of GM 1 introduced. Calculating the heat of decomposition from this equation we obtain values of 484 and 473 kcal/kg. respectively. These are of the same order as the values mentioned above. This consideration assumes that the efficiency of the process is the same both for operation with and without GM 1.

In order to arrive at general relationships we have plotted the output lines of figs. 4 and 5 against the excess oxygen ratio λ . (For the sake of uniformity we shall always use the excess oxygen ratio here; in this case of operation without GM 1 this is of course equivalent to the excess air ratio). The calculation of λ was based on the theoretical quantity of air used up in the combustion of fuel C 3 employed here, viz. about 14.75 kcal/kg; also on the total air consumption, inclusive of the scavenging air which is not covered and which may be expected at a valve overlap of 96° crank angle with T.D.C.

The lines show but little difference between normal and GM 1 operation. As usual the maximum of the output is at about $\lambda = 0.8$.

3. The temperature conditions.

Apart from the output figures the corresponding temperature lines have been entered into figs. 6 and 7. The exhaust temperatures were measured for the cylinders 1 and 7 immediately behind the exhaust pipe by means of thermo-elements; similarly the temperatures of the seats of the sparking plugs were measured by means of thermoelements for the cylinders 1, 5, 7 and 11. The temperature at which the cooling water entered was kept constant for all the measurements.

Let us compare points having the same excess oxygen ratio λ : when GM 1 is added to the charge the exhaust temperatures lie about 30° higher than during normal operation at the same output; the difference at the seats of the plugs is about 10°. Increases of temperature much higher than those occurring at the well cooled seats of the ignition plug will be produced by GM 1 at parts having worse heat transfer, such as the piston, the exhaust valves etc. In particular, the temperature rise at the outlet valves will be greater than the value of 30° measured in the exhaust gas immediately behind the valves. This is due to the fact that proportional to the cooling of the exhaust gases during their outward flow there is a fall of the temperature difference for the two methods of operation; the temperature rise due to GM 1 would thus be more than 30° if it were measured directly in the section of the valve. We may thus estimate that the temperature rise at the outlet valve, the largest occurring anywhere, will be about 40 to 50°.

Enrichment of the mixture produces a depression of the temperature for GM 1 operation quite similar to that for normal operation. To carry out such an enrichment would have a particularly favourable effect on the outlet valve since enrichment also diminishes the after-burning. In this way the exhaust gas temperatures are reduced even further than the other temperatures.

Finally let us consider the course of the temperature along the whole working cycle. For equal temperatures in front of the blower the boost air temperatures are lower when GM 1 is added than for normal operation; in the instances discussed above the difference is 13 and 17°C respectively. These temperature differences become less when the gases flow into the cylinder because then the residual gases and the walls exert a greater influence. This is so because of the greater temperature gap between the colder charge in GM 1 operation to the hotter walls and residual gases. During compression the temperature difference again increases as may immediately be shown from the Polytropic equation. The cylinder contents at the end of the compression are colder if GM 1 is used. The energy liberated during the combustion with and without GM 1 is the same for a given output; the weight of gas present, however is considerably less, so that the heating up is greater. Thus the maximum temperature reached at the end of the combustion will be higher for operation with GM 1. The excess of temperature connected with the addition of GM 1 falls back to the 300 measured behind the valves during the expansion and exhaust stroke.

4. Quantity of heat carried away in the cooling water.

The quantity of heat relative to the output carried away by the cooling water in each hour is plotted against the excess oxygen ratio number in figs. 8 and 9. It is shown that more heat is carried away when GM 1 has been added; this corresponds to the higher temperature involved. It is possible to diminish this accruing heat which has to be dealt with by the radiator by enrichment.

III. Summary.

The investigation covered the thermal and mechanical stress on the engine when GM 1 is added to the charge. The influence of ignition timing on the output and loading were also investigated. It appears that in order to obtain the optimum performance and the lowest loading it is necessary to undertake a special adjustment of the ignition timing to the conditions of GM 1 operation. During GM 1 operation the thermal loading is somewhat higher than it is during normal operation giving the same output.

Fig. 1 - Output, maximum combustion pressure, position of the combustion peak as a function of ignition timing;
n = 2500 revs/min.; height 10 km.; operation with and without GM 1.
Left ordinates: Position of the combustion peak; effective power.
Right ordinate: Maximum combustion pressure.
Abscissa : Time of ignition.

Fig. 2 - Maximum combustion pressure against piston path.
n = 2500 revs/min.; height 10 km.; operation with and without GM 1.
Ordinate: Maximum combustion pressure.
Abscissa: Path traversed by piston up to the instant of greatest combustion measured in mm. from top centre.
Inscription: Lines of equal times of ignition.
Inset: Points of optimum output.
Addition
Normal operation,
Increased output.

Fig. 3 - Indicator diagrams for operation with and without GM 1.
Ignition timing: 35° B.T.C., n = 2500 revs/min.
Height 10 km.
Normal operation 105 gm/sec GM 1 addition Normal operation increased output.

Fig. 4 - Combustion loops with 80 gm/sec GM 1 and without GM 1
n = 2500 revs/min. Height 10 km.
Ordinate: Effective power N_e
Abscissa: Specific fuel consumption gm/HP_eh
Inset : 80 gm GM 1 addition.
Normal operation, increased output.

Fig. 5 - as fig. 4.

Fig. 6 - Output, exhaust temperature and temperature at plug seat against excess oxygen ratio λ.
n = 2500 revs/min., height 10 km., operation with 80 gm/sec GM 1 and without GM 1
Ordinates upwards: Temperature at plug seat, exhaust temperature, effective power.
Abscissa : Excess oxygen ratio λ.
Inset: 80 gm/sec GM 1 addition.
Normal operation with increased output.

Fig. 7 - as fig. 6.

Fig. 8 - Quantity of heat carried away by the cooling water for each $H.P._e h.$
n = 2500 revs/min; height 10 km., with 80 gm/sec GM 1 and without GM 1 (for equal output; DB 601 Q)
Ordinate: Heat carried away.
Abscissa: Excess oxygen ratio.
Inset : 80 gm/sec GM 1 addition.
Normal operation, increased output.

Fig. 9 - as fig. 8.