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No. 795

EFFECT OF SEVERAL SUPERCHARGER CONTROL METHODS ON ENGINE PERFORMANCE

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SUMMARY

The following superchargers, all applied to the same hypothetical engine, have been compared analytically: a single-speed, a two-speed, and a variable-speed DVL centrifugal supercharger; the Szydlowski-Planiol supercharger with both a single-speed and a two-speed transmission; and a turbosupercharger. A constant manifold pressure was maintained to the critical altitude.

From the calculations that were made, it is concluded that the variable-speed DVL supercharger, the Szydlowski-Planiol supercharger (with a two-speed transmission), and the turbosupercharger (furnished with exhaust gas at 1500° F and having an efficiency of 50 percent) give larger propeller powers below the critical altitude than either the single-speed or the two-speed DVL supercharger. For all cases the increase in power over that obtained with the two-speed DVL centrifugal supercharger is partly offset by the power loss due to the additional weight. This weight increase is small for the variable-speed and the Szydlowski-Planiol superchargers; in the case of the turbosupercharger, it is an appreciable disadvantage. In the case of the variable-speed DVL supercharger, the exact amount of gain in power also depends on the power required for the dissipation of waste heat in the oil cooler. When these various systems of supercharging are applied for a condition of constant charge weight, which gives approximately constant engine stress up to the critical altitude, their relative merits also depend on the power loss due to the intercoolers required.

If all the losses mentioned are neglected, a large increase in propeller power over the power given by the two-speed DVL supercharger (in the vicinity of the gear-shift point) can be realized with the turbosupercharger (which showed the largest gain), the variable-speed DVL supercharger, and the Szydlowski-Planiol supercharger.

INTRODUCTION

If a given engine is equipped with various single-speed superchargers, the power delivered to the propeller at any altitude below the critical will decrease as the critical altitude of the supercharger increases. This statement is true because the temperature rise in a single-speed supercharger is nearly constant at all altitudes. The constant temperature rise results in a large decrease in propeller power near the ground, owing to the decreased charge weight at a given manifold pressure and to the knocking limitations caused by the high engine inlet temperature as well as to the relatively large amount of power required by the supercharger. Since the temperature rise increases with the critical altitude of the supercharger, a drop in propeller power below the critical altitude will accompany an increase in the critical altitude.

On present-day engines, the two-speed supercharger and the turbosupercharger are used to improve this situation. Two new means have recently been advanced: the Szydlowski-Planiol supercharger (reference 1) and the planetary variable-speed transmission.

In this report, an analytical comparison of all these means has been made, under various operating conditions, for superchargers capable of maintaining sea-level pressure to approximately 25,000 feet. A description of the new means of supercharging is included.

DESCRIPTION OF UNITS CONSIDERED

The following combinations were considered in this report: a DVL centrifugal supercharger with a single-speed, a two-speed, a variable-speed, and a turbine drive; and a Szydlowski-Planiol supercharger with a single-speed and a two-speed drive.

The single-speed and the two-speed superchargers and the turbosupercharger were assumed to be the conventional types in use at present. Control in the first two types is obtained by throttling the inlet and, in the third type, by means of a waste gate in the engine-exhaust pipe.

The use of epicyclic gearing to obtain a variable-speed transmission is possible with a number of different arrangements; all these arrangements, however, are the same in principle and give the same theoretical efficiency.

In order to illustrate the principles involved, a simplified diagram of a drive proposed by Szekely is shown in figure 1. This planetary gear system consists of the spider A that is integral with the drive shaft; pinion B; gear D, which floats on the drive shaft; and the internal gear K, to which the supercharger rotor is attached. Gear F is integral with gear D and together with pinion G forms an oil pump that serves to load gear D. The overrunning clutch E is not essential but is merely a detail of this design; it serves to prevent the supercharger rotor from turning at a lower speed than the drive shaft.

The speed of the drive shaft A is the same as the low speed of an ordinary two-speed supercharger. If there is no resistance to the motion of D, it will rotate at a high speed and K will be at rest. By means of the oil pump, a load can be placed on gear D, causing it to slow down. As a result of the decrease in speed of D, the gear K is made to rotate faster, the speed of A being constant. When D is stationary, K attains its maximum speed. In practice, however, there is leakage in the pump and D cannot be completely stopped. The maximum attainable supercharger speed with a given set of gear will, therefore, be somewhat lower than the maximum speed. For the general case, the speed is variable down to zero; on account of the clutch, the minimum speed is the same as the speed of the drive shaft. It is evident that, in general, any intermediate speed can be obtained with a planetary gear system by controlling the speed of one of the gears.

The efficiency of the variable-speed drive is determined by the power required to hold the center gear D at a speed that will give the desired overdrive. The power supplied to the shaft A goes to the supercharger and to the shaft D from which the oil pump is driven. If Q and N are used to denote torque and speed, respectively,

$$Q_A N_A = Q_K N_K + Q_D N_D$$

where the subscripts refer to the components of the transmission (fig. 1). Also, from the equilibrium condition for pinion B,

$$Q_A = Q_K + Q_D$$

These two equations are combined to obtain an expression for the power P required by the shaft D:

$$P_D = \frac{N_D}{N_K}\,\frac{N_K - N_A}{N_A - N_D}\,P_K$$

The factor $\dfrac{N_K - N_A}{N_A - N_D}$ is the train ratio M, which is constant for a given set of gears. Substitute

$$\frac{P_D}{P_K} = \frac{N_A + MN_A - N_K}{N_K}$$

The quantity $N_A + MN_A = N_{K_{max}}$, the maximum speed of K, which is reached when $N_D = 0$. Thus, the losses as a fraction of the supercharger power are

$$\frac{P_D}{P_K} = \frac{N_{K_{max}} - N_K}{N_K} \qquad (1)$$

For a given set of gears and shaft speed, the efficiency of the drive is a function only of the supercharger speed. If there were no slippage, $N_{K_{max}}$ would be the maximum supercharger speed. With the transmission shown in figure 1, however, the shaft D cannot be brought to rest, and it is necessary to make $N_{K_{max}}$ slightly higher than the highest supercharger speed; the effect of this condition is to lower somewhat the efficiency of the drive.

For the calculations in this paper, the single-speed, the two-speed, and the variable-speed drives were applied to the DVL supercharger described in reference 2. This supercharger is of the centrifugal type, having a fully shrouded impeller and inlet vanes mounted on a separate wheel keyed to the impeller. The characteristics of this supercharger are shown in figure 2 (from reference 2), which gives H_{ad} and η_{ad} as a function of V_1 for several speeds where

H_{ad} adiabatic work required to compress 1 pound of air in foot-pounds per pound given by

$$H_{ad} = \frac{\gamma}{\gamma - 1} RT_i \left[\left(\frac{p_o}{p_i} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \tag{2}$$

γ	ratio of specific heats (c_p/c_v)
c_p	specific heat of air at constant pressure, Btu per pound per degree Fahrenheit
c_v	specific heat of air at constant volume, Btu per pound per degree Fahrenheit
R	gas constant
T_i	temperature of the air entering the supercharger, degrees absolute
p_i	absolute pressure of air entering supercharger, pounds per square foot
p_o	absolute pressure of air leaving supercharger, pounds per square foot
V_i	inlet volume, cubic feet per second
η_{ad}	adiabatic efficiency based on temperatures given by $\eta_{ad} = \dfrac{\text{adiabatic temperature rise}}{\text{actual temperature rise}}$ (also defined by equation (4))

The Szydlowski-Planiol supercharger (reference 1), to which both single-speed and two-speed drives were applied, is a combination of several axial-flow wheels with a centrifugal impeller. A cross section of this supercharger is shown in figure 3. The centrifugal impeller is indicated by P; R_1, R_2, and R_3 are axial-flow wheels keyed to the same shaft. Two entrances, E_p and E_s, contain guide vanes, the angles of which are adjustable. Near the critical altitude, the air enters at E_p. The position of the guide vanes is such as to make $\beta < 0$ (where β is the angle of attack of the blades of wheel R_1); R_1 then acts as a compressor. As the required pressure ratio becomes smaller (below the critical altitude), the guide vanes in E_p are so operated that the blades of R_1 are made to act first as neutral blades $(\beta = 0)$ and finally as turbine blades $(\beta > 0)$. In this last case, some of the energy normally lost in throttling is used to help drive the supercharger. For very low pressure ratios, the air enters at E_s, where it can be given the proper whirl for shockless entrance into P.

The characteristics of this supercharger are shown in figure 4. In this case the adiabatic efficiency is given as a function of the adiabatic temperature rise for various tip speeds for a condition of constant outlet pressure and constant weight of air pumped (reference 3). The adiabatic temperature rise is defined by

$$\Delta T = T_i \left[\left(\frac{p_o}{p_i}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \qquad (2a)$$

METHODS

The atmospheric data given in reference 4 were used to make calculations for two manifold pressures: 29.92 and 40 inches of mercury absolute. For each of these pressures, two cases were considered: (1) supercharger without intercooling, and (2) supercharger with sufficient intercooling to give constant charge weight from the sea level to the critical altitude. The first case corresponds to a conventional supercharger installation, and the second imposes approximately constant stress upon the engine to the critical altitude. For the case of constant charge weight (case 2), cooling was assumed to be sufficient above the critical altitude to lower the engine inlet temperature by the same fraction of the total thermal head (difference between supercharger outlet and atmospheric temperature) as at the critical altitude. For the two-speed supercharger, the transition curve from the low-speed critical altitude to the point at which the gear change is made (see figs. 8 and 14, to be discussed later) was obtained by assuming that the engine inlet temperature was lowered by 40 percent of the thermal head; large deviations from this value change the curve very little.

Supercharger Calculations

Each method of supercharging was applied to the same hypothetical engine, the displacement of which was obtained by a method described later. The manifold temperature, the back pressure (for the turbosupercharger), and the power required by the supercharger were calculated; for the cooled condition, the amount of intercooling required was obtained from the temperature drop and the specific heat of air. Inasmuch as these supercharger characteristics are based on temperature measurements, the supercharger power obtained from figure 2 was divided by 0.95 to account for losses not appearing in the temperature. The efficiency of the low-speed gears was taken as 90 percent; that of the high-speed gears was taken as 85 percent.

Single-speed DVL supercharger.- The single-speed supercharger was assumed to be driven at 26,700 rpm. In order to determine the critical altitude, the supercharger was assumed to operate at maximum efficiency at this speed. The critical altitude, then, is the one where the value of H_{ad} from equation (2) is the same as that picked from the curve. The complete supercharger conditions were obtained from the following equations:

$$\frac{T_{o_{ad}}}{T_i} = \left(\frac{p_o}{p_i}\right)^{\frac{\gamma-1}{\gamma}} \tag{3}$$

$$\frac{T_{o_{ad}} - T_i}{T_o - T_i} = \eta_{ad} \tag{4}$$

$$pv = WRT \tag{5}$$

where $T_{o_{ad}}$ adiabatic exit temperature, degrees absolute

T_o actual exit temperature, degrees absolute

p pressure, pounds per square foot absolute

v volume, cubic feet

W weight, pounds

T temperature, degrees absolute

The displacement of the engine can be found from the equation (from reference 5, changed to American notation):

$$v_i = v_E \left[1 + \frac{1 - \frac{p_e}{p_o}}{\gamma(r - 1)} \right] \tag{6}$$

where v_i volume of the charge entering engine, cubic feet per second

v_E displacement of engine, cubic feet per second

r compression ratio

p_e exhaust back pressure, pounds per square foot absolute

A value of $\gamma(r - 1)$ equal to 7.7 was assumed. The value of the engine displacement, found from the conditions at the critical altitude for sea-level manifold pressure and equation (6), was used in all subsequent calculations.

By means of equations (2), (3), (4), (5), and (6), calculations can be made for the conditions below and above the critical altitude for all cases considered. Below the critical altitude, the supercharger is throttled at the inlet; above the critical altitude, there is no throttling, but the speed is held at 26,700 rpm.

Two-speed DVL supercharger.- The two-speed supercharger was assumed to have speeds of 15,000 and 26,700 rpm. Since performance at the high speed can be obtained from the single-speed case, calculations need be made only for the low speed. Above the first critical altitude, the supercharger is held at 15,000 rpm until the gear-shift point is reached. Calculations are made in the same way as for the single-speed supercharger.

Turbosupercharger.- At all altitudes, the efficiency of the turbine was assumed to be 50 percent with an exhaust temperature of 1500° F. The maximum allowable speed was taken as 26,700 rpm, and the calculations at and above the critical altitude were made for this speed.

In order to find the engine back pressure and the supercharger operating point, the condition that must be satisfied is the equality of the supercharger power and the turbine output. The total power required by the supercharger is

$$P_s = \frac{W_a H_{ad}}{0.95\ \eta_{ad}}$$

where P_s total supercharger power, foot-pounds per second

W_a weight of air flowing, pounds per second

0.95 factor to account for work not appearing as rise in temperature

This value of P_s must be equal at all times to the power P_t expended by the turbine,

$$P_t = W_e\, c_p (1960 - T_{e_{ad}}) 778 \times 0.5$$

where the temperature at the end of an adiabatic expansion $T_{e_{ad}}$ is given by

$$\frac{T_{e_{ad}}}{T_e} = \left(\frac{p_i}{p_e}\right)^{\frac{\gamma-1}{\gamma}}$$

P_t total turbine power, foot-pounds per second

W_e weight of exhaust gas, pounds per second

The value 778 is the mechanical equivalent of heat, foot-pounds per Btu.

The weight of the exhaust gas is found by the use of the equations for short tubes as given in reference 6. The values of c_p and R for the exhaust gas are 0.289 and 53.81, respectively, in accordance with data given in reference 7; these data are based on the assumption that the exhaust gas consists of 13 percent CO_2, 14 percent H_2O, and 73 percent N_2 by weight. If P_t is set equal to P_s and the resulting equation is combined with equations (2), (3), (4), (5), and (6), a solution can be obtained for all altitudes for the turbosupercharger.

Variable-speed DVL supercharger.- The power loss for the supercharger with the variable-speed drive was calculated from figure 2 and equation (1) on the assumption that a slippage of 4 percent was present. Figure 5 gives the losses for the various conditions for a drive infinitely variable from 0 to full speed (26,700 rpm). The losses for the drive with overrunning clutch occur at speeds between 15,000 and 26,700 rpm. The supercharger operating points can be found at all altitudes by the use of the curves in figure 2 and equations (2), (3), (4), (5), and (6). As with the turbosupercharger, there is no throttling, and the speed is limited to 26,700 rpm.

Szydlowski-Planiol supercharger.- Because the characteristic curves of the Szydlowski-Planiol supercharger are given only for the condition of constant charge weight, calculations were made only for this condition; no calculations were made above the critical altitude for this supercharger. Figure 6 (from reference 1) shows the altitude to which sea-level pressure can be maintained with the DVL, the Szydlowski-Planiol, and the ideal radial-blade superchargers. The operating speed of the Szydlowski-Planiol supercharger was chosen from this curve to give the same critical altitude as the DVL supercharger. By means of figures 5 and 6 and equations (2a) to (6), calculations can be made as before for both the single-speed and the two-speed drives.

Engine and Power Calculations

No account was taken of the effect of the evaporation of the fuel. The gross engine horsepower was assumed to be proportional to the weight of air inducted; a factor of 550 horsepower per pound of air per second at sea level was used. The propeller power is the difference between the gross engine power and the power required for the supercharger. No allowance was made for the power required by intercoolers or oil coolers (variable-speed drive). Correction for the increase in charge due to decreased back pressure was made by means of equation (6). The increased power due to the work done by the supercharger on the intake stroke and the decrease in back pressure was taken as

$$\Delta P = \frac{\Delta p \; v_E}{550}$$

where ΔP is the gain in horsepower and Δp is the difference between the intake and the exhaust pressures, pounds per square foot. Although this method does not give an exact value for the propeller power, it is sufficiently accurate for purposes of comparison.

In order to find the relative fuel condumptions of the cases considered, an over-all efficiency factor was obtained. This factor is the ratio of the propeller power to the gross engine power.

RESULTS AND DISCUSSION

The assumptions made in regard to the power gain due to the change in pressure at the engine inlet and exhaust are applied to the same extent for all gear-driven examples. These assumptions, however, have a different effect on the turbosupercharger and, as a result, the relative performance of this unit is somewhat better than will be indicated because the gain in power due to lowering the back pressure is less than the value assumed.

Sea-level manifold pressure to the critical altitude.- The propeller power obtained with each method of supercharging with no intercooling is shown in figure 7 for sea-level manifold pressure. The unsuitability of the single-speed supercharger is immediately obvious because of the small power obtained at low altitudes. The possibilities of the variable-speed drive are shown by the curve for the ideal case.

The two-speed supercharger shows marked improvement in propeller power, especially near the low-speed critical altitude. Changing the gear ratio will give the low-speed power peak at any desired altitude; the two parts of the low-speed curve will be shifted to a new position but will remain approximately parallel to the lines shown in the figure. Thus, an increase in the low-speed critical altitude can be obtained at the expense of the power near the ground.

Regardless of the gear ratio chosen, the variable-speed supercharger and the turbosupercharger show a considerable advantage (as much as 20 percent at the gear-shift point) over the two-speed supercharger. With an overrunning clutch as in figure 1, however, there is an advantage only above the low-speed critical altitude, since the variable-speed drive is not used below 10,000 feet. A supercharger having a drive variable from zero to full speed gives better low-altitude performance than the two-speed supercharger and the turbosupercharger. The propeller power for the variable-speed drive will be lowered because of the power required to dissipate the waste heat in an oil cooler. (See fig. 5.) The total oil-cooling capacity required will be about twice that of an engine with a two-speed supercharger. It is interesting to note that, even if the power required because of the additional cooling requirements were as great as the power to be dissipated, the variable-speed drive would still show a markedly higher propeller power than the two-speed supercharger at certain altitudes.

The propeller power for the turbosupercharger and the variable-speed supercharger is decreased by the power required to carry the additional weight of these units; the amount of extra weight will be about 200 pounds for the turbosupercharger and about 10 pounds (not including cooler) for the supercharger with a variable-speed drive. The corrections due to this weight, however, will be small compared with the gain in propeller power, and both these superchargers can be expected to give a substantial increase in power over the two-speed supercharger. This increase is obtained, especially in the case of the turbosupercharger, at the expense of increased weight per horsepower at some altitudes.

Figure 8 shows the propeller power for the condition of constant charge weight below the critical altitude. The beneficial effect of cooling the charge to constant weight is especially noticeable for the single-speed DVL supercharger, but it is still considerably inferior to the other methods of supercharging. Both the turbosupercharger and the single-speed Szydlowski-Planiol supercharger approach constant propeller power below the critical altitude although considerably more power is obtained with the turbosupercharger; this superiority persists above the critical altitude, since the power curve above the critical altitude for the Szydlowski-Planiol supercharger can be considered to be approximately parallel to that of the DVL supercharger. Between the first and the second critical altitudes, the Szydlowski-Planiol supercharger produces somewhat greater propeller power than the DVL variable-speed supercharger. This greater power is due to the relatively low efficiency of the DVL supercharger at high speed. Slight corrections must again be made for additional weight; although no values are available, the extra weight of the Szydlowski-Planiol supercharger is probably about 30 pounds. There will be a slight increase in weight per horsepower of the DVL variable-speed and the Szydlowski-Planiol superchargers as compared with a two-speed supercharger, but only near the critical altitudes.

The conclusions obtained from figure 8 must be modified to take into account the intercooling requirements shown in figure 9. The large amount of cooling required by the single-speed DVL supercharger, which is about twice that required by the single-speed Szydlowski-Planiol supercharger, considerably lowers the propeller power. As a result of the intercooling requirements, the advantage of the turbosupercharger is somewhat reduced. The general trend, however, will quite certainly be the same; the best results will be obtained with the two-speed Szydlowski-Planiol supercharger; the DVL variable-speed superchargers, and the turbosupercharger, with the turbosupercharger producing slightly more propeller power than the others. On the other hand, the practical disadvantages of the turbosupercharger will make it somewhat less desirable than the analysis indicates.

The manifold temperatures for the different superchargers are shown in figure 10. The high temperature shown by the single-speed and the two-speed DVL superchargers in the uncooled case will probably necessitate a reduction in the propeller power owing to the limitations imposed by knock. All gear-driven superchargers follow the same temperature curve for the constant charge-weight case except for the slight deviation made by both two-speed superchargers near the low-speed critical altitude.

The relative values of the fuel consumption as indicated by the over-all efficiency factor are illustrated in figure 11. The marked advantage of the turbosupercharger in this respect is immediately evident. Cooling is shown to have practically no effect because the curves for both the cooled and the uncooled conditions are either superposed or very close to each other. In fact, because of the horsepower required for cooling, the fuel consumption for the cooled cases will be higher.

The engine back pressure for the turbosupercharger is shown in figure 12. The pressure falls below 29.92 inches of mercury at about 5000 feet. The waste gate is fully closed at the critical altitude but must be opened again above the critical altitude in order to prevent the turbine from overspeeding.

<u>Manifold pressure of 40 inches of mercury to the critical altitude.</u>- Figure 13 shows the propeller power obtained without intercooling for a manifold pressure of 40 inches of mercury. As in the case of sea-level manifold

pressure, the advantage of the turbosupercharger and the variable-speed supercharger is clearly shown. In this case, however, the drive with an overrunning clutch is shown to better advantage than with sea-level manifold pressure because the low-speed critical altitude is near the ground.

The propeller power for the case of 40 inches of mercury manifold pressure and constant charge weight is shown in figure 14. The curves show that the difference between the variable-speed DVL supercharger and the two-speed Szydlowski-Planiol supercharger is small, the variable-speed supercharger again being at a disadvantage near the critical altitude because of the low efficiency of the DVL supercharger at high speeds.

If the intercooler requirements shown in figure 15 and the power due to additional weight as well as the power required for dissipating the waste heat of the variable-speed drive are taken into account, the two-speed Szydlowski-Planiol supercharger probably produces greater power at all altitudes than the DVL supercharger with the variable-speed drive. The large amount of cooling required by the turbosupercharger will again bring the propeller-power curve closer to the others.

The manifold temperatures are shown in figure 16. The propeller power for both the single-speed and the two-speed DVL superchargers will probably be lessened because of the limitations imposed by combustion knock. Knock may also limit the power for the variable-speed supercharger and the turbosupercharger. It will be impossible to utilize a manifold pressure of 40 inches of mercury without cooling. As before, the manifold temperatures for all the gear-driven superchargers with constant charge weight fall on the same curve, with the exception of the two-speed superchargers near the low-speed critical altitude.

Figure 17 illustrates the greater efficiency of the turbosupercharger for the manifold pressure of 40 inches of mercury. Of all the gear-driven superchargers considered, the Szydlowski-Planiol will probably give the least fuel consumption over a wide range when all factors are considered.

The engine back pressure for the higher manifold pressure is shown in figure 18. The difference between the manifold and the back pressures is somewhat smaller near the critical altitude for a manifold pressure of 40 inches of mercury than it is for 29.92 inches of mercury. The increased power available owing to the higher pressure drop across the turbine is more than balanced by the increased supercharger work that must be done.

CONCLUSIONS

For the supercharging conditions considered in this report, an analytical study shows:

1. When the power required to dissipate the waste heat was neglected, a DVL supercharger having a variable-speed drive showed considerable improvement in performance over a DVL two-speed supercharger. The increase in propeller power can be as much as 20 percent in a favorable case, the greatest improvement occurring at the gear-shift point.

2. The Szydlowski-Planiol supercharger equipped with a two-speed drive gave a calculated performance approximately the same as that of the DVL supercharger with a variable-speed drive when it was assumed that any effects due to increase in weight may be neglected.

3. An exhaust-gas turbine receiving gas at 1500° F and having an efficiency of 50 percent showed better performance at all altitudes than either the variable-speed or the Szydlowski-Planiol supercharger with either single- or two-speed drive when the effects due to the increase in weight were neglected.

4. The exact amount of gain in propeller power over the DVL two-speed supercharger will be determined by the power required to dissipate (in an oil cooler) the waste heat for the DVL variable-speed supercharger by the increase in the weight of the installation for all superchargers and by the intercooler power for the conditions of constant charge weight. The extra weight of the supercharger and drive is negligible for the DVL variable-speed and the Szydlowski-Planiol superchargers, but for the turbosupercharger, it is an appreciable disadvantage.

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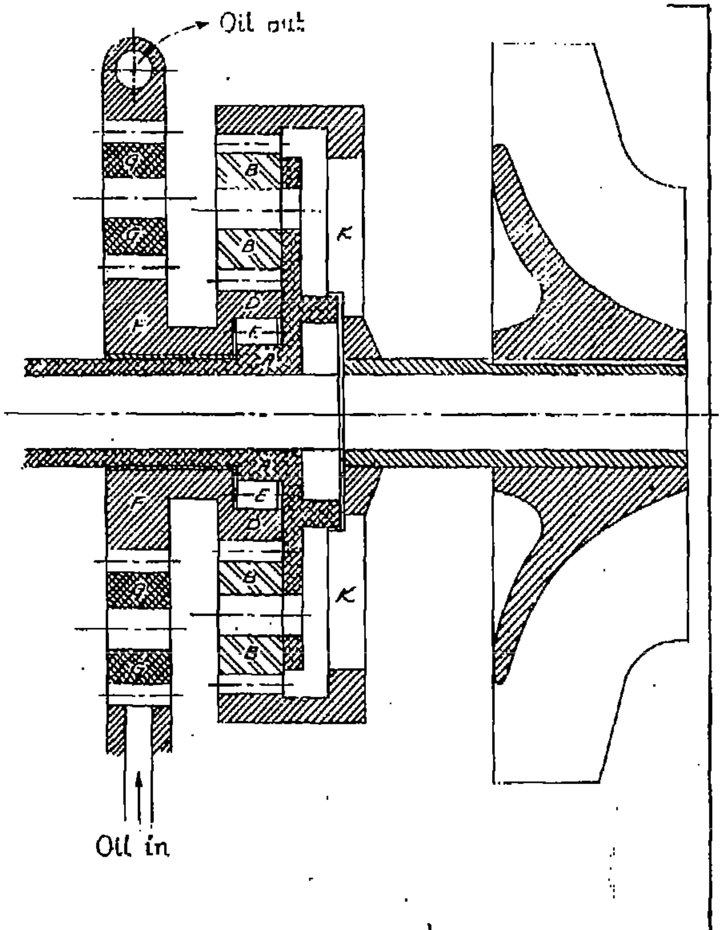

Figure 1.-Szekely variable-speed transmission.

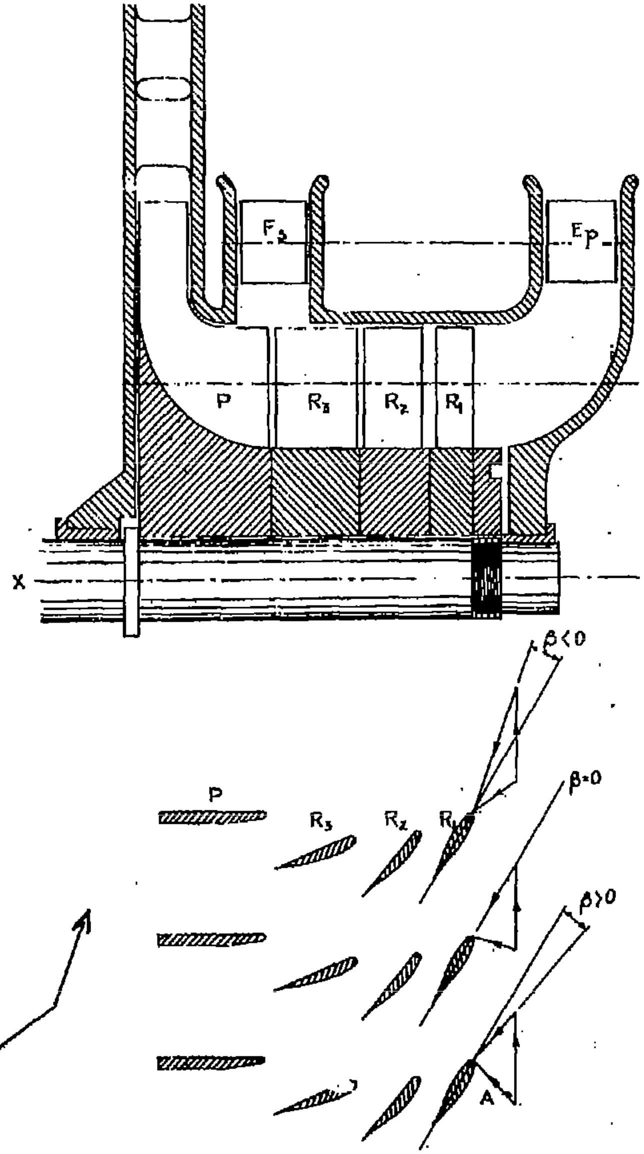

Figure 3.- Szydlowski-Planiol supercharger
(From reference 1.)

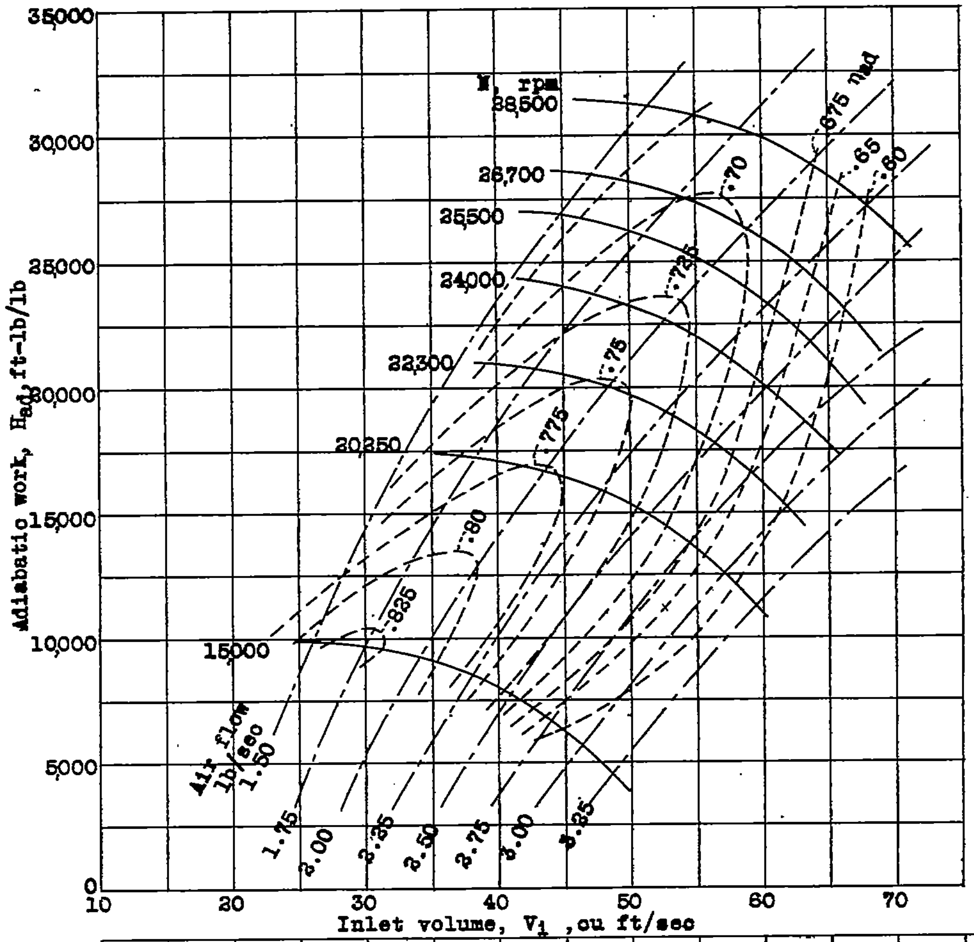

Figure 2.- . characteristics of DVL supercharger. (From reference 2.)

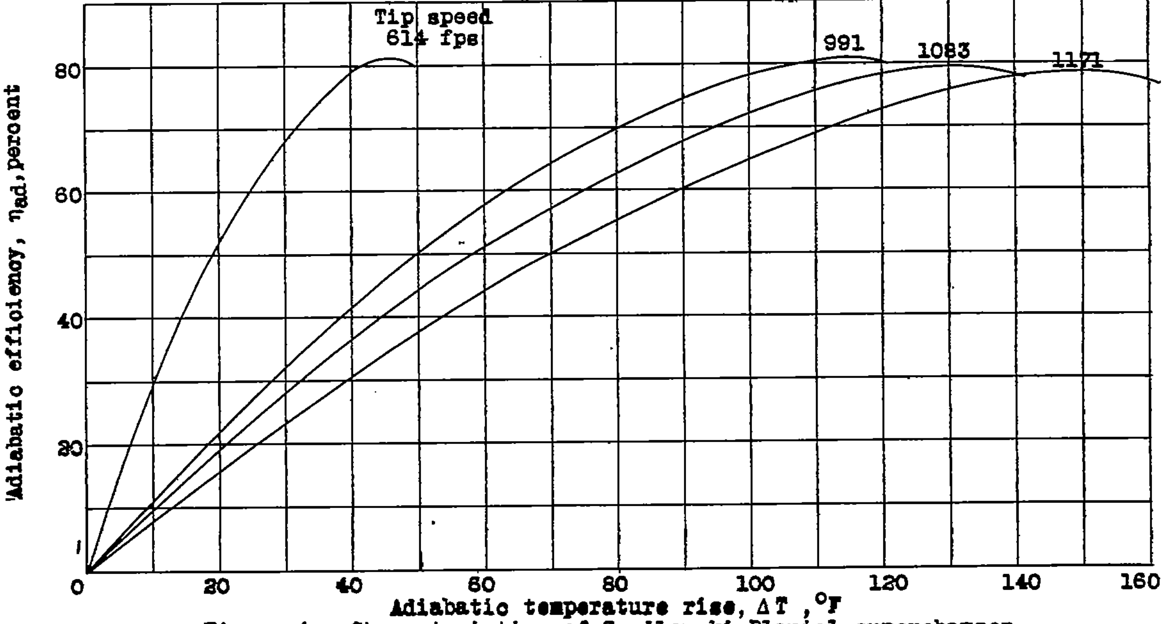

Figure 4.- Characteristics of Szydlowski-Planiol supercharger. (From reference 1.)

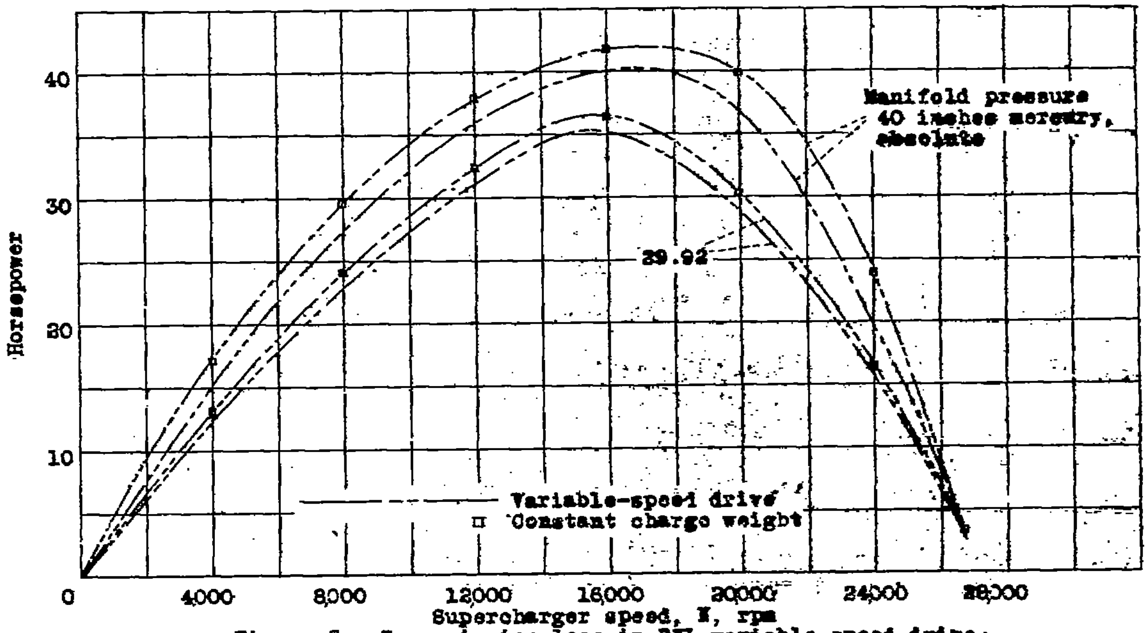

Figure 5.- Transmission loss in DVL variable-speed drive.

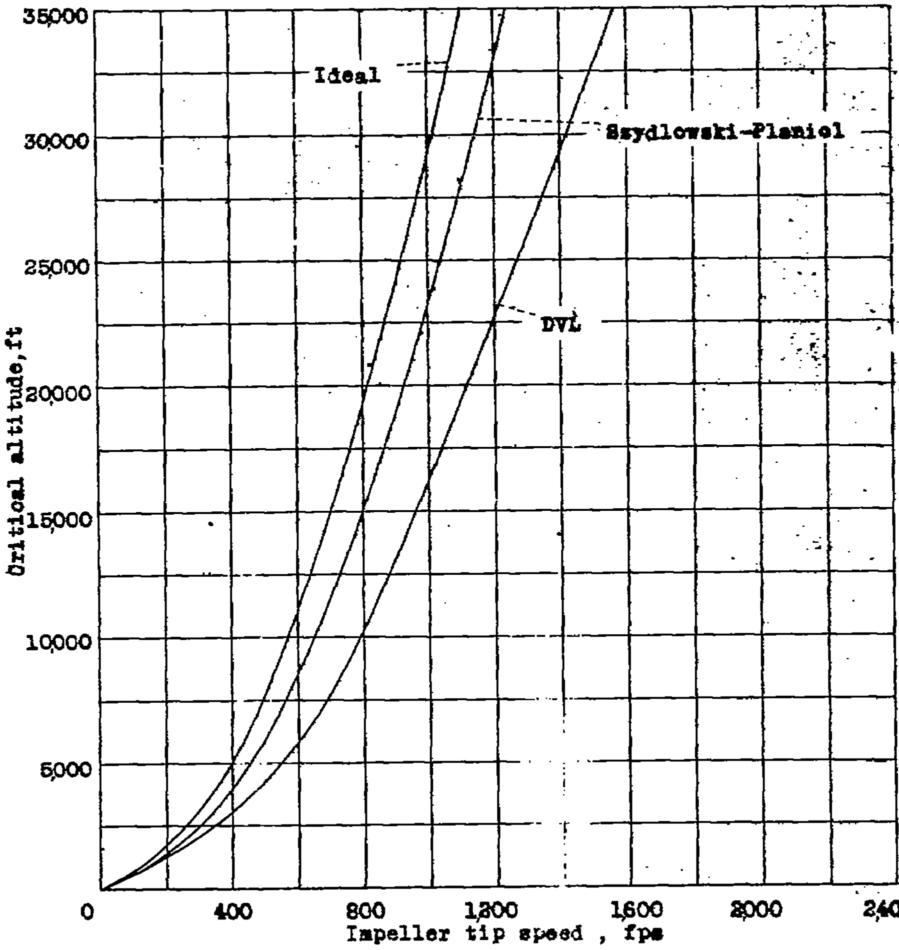

Figure 6.- Altitudes to which sea-level pressure can be maintained with the DVL, the Szydlowski-Planiol, and the ideal radial-blade superchargers. (From reference 1).

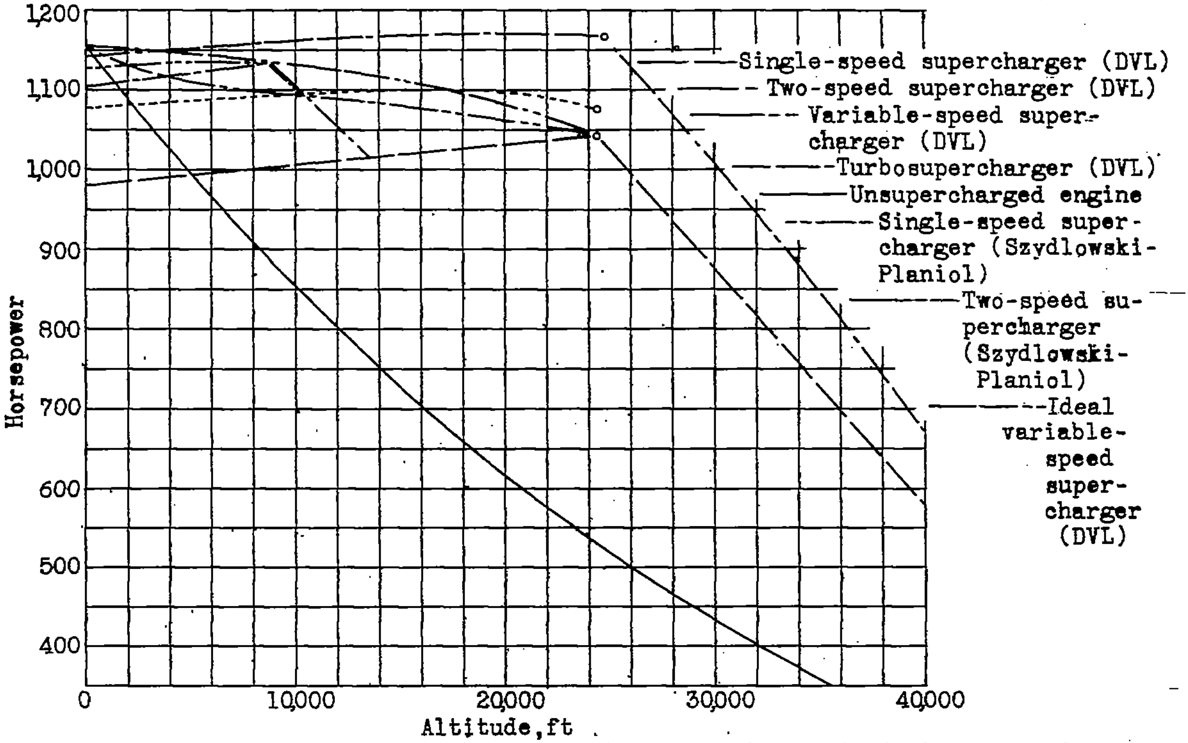

Figure 8.- Variation of propeller power with altitude,constant charge weight. Manifold pressure below critical altitude,29.92 inches of mercury.

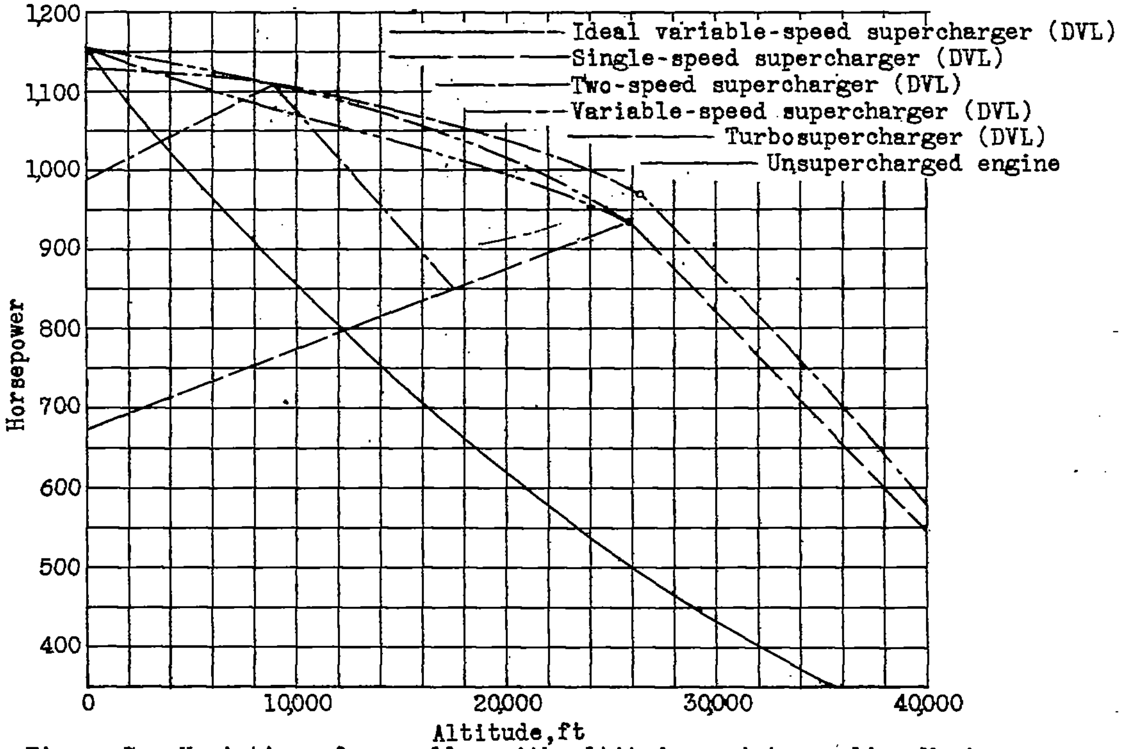

Figure 7.- Variation of propeller with altitude,no intercooling.Manifold pressure below critical altitude,29.92 inches of mercury.

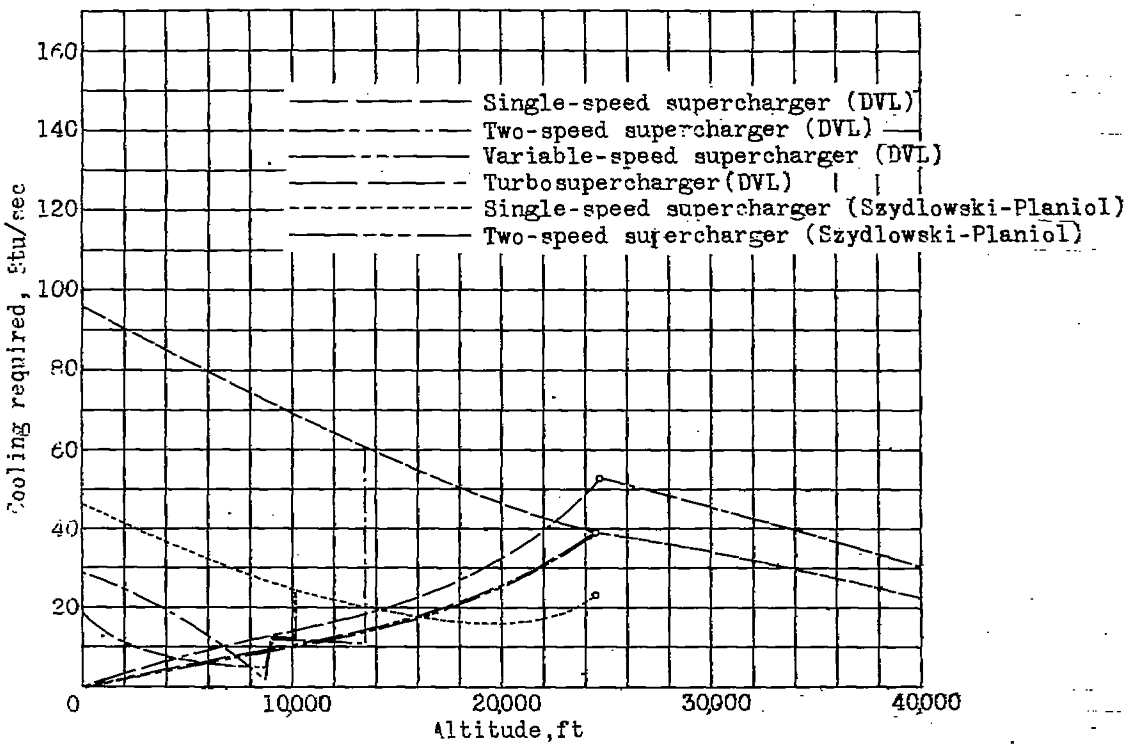

Figure 9.- Amount of intercooling required for various superchargers. Manifold pressure below critical altitude, 29.92 inches of mercury.

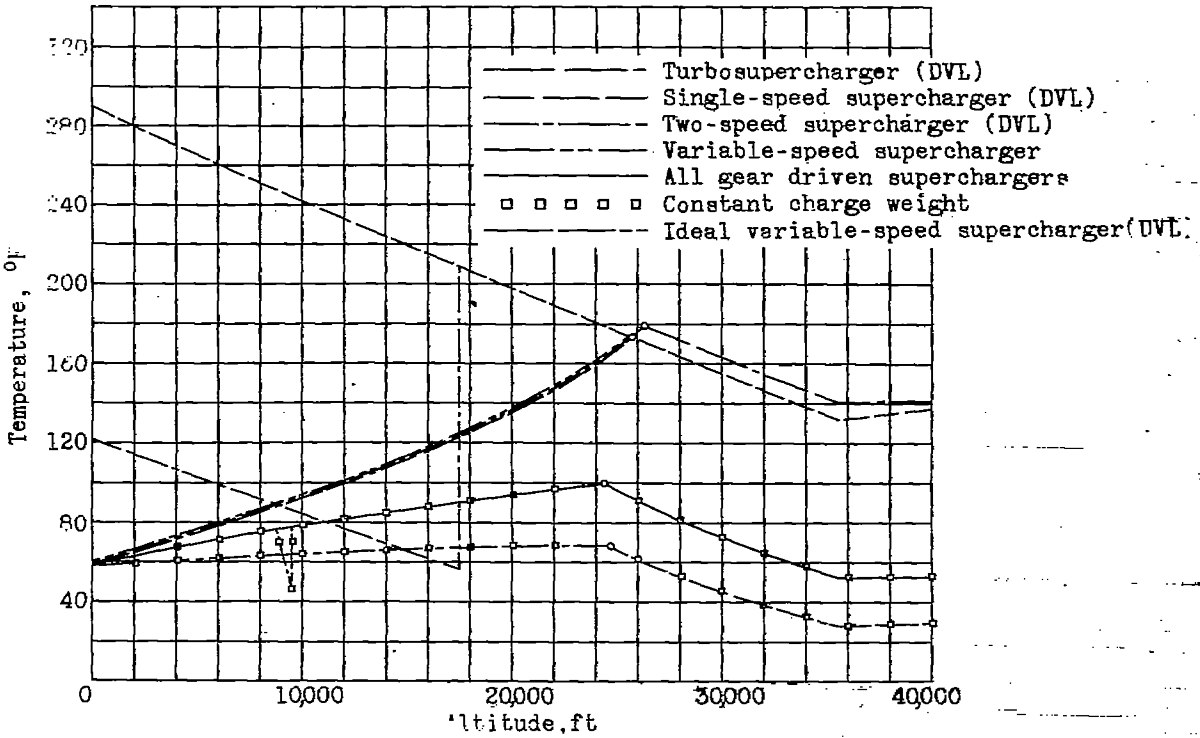

Figure 10.- Manifold temperature for various superchargers. Manifold pressure below critical altitude, 29.92 inches of mercury.

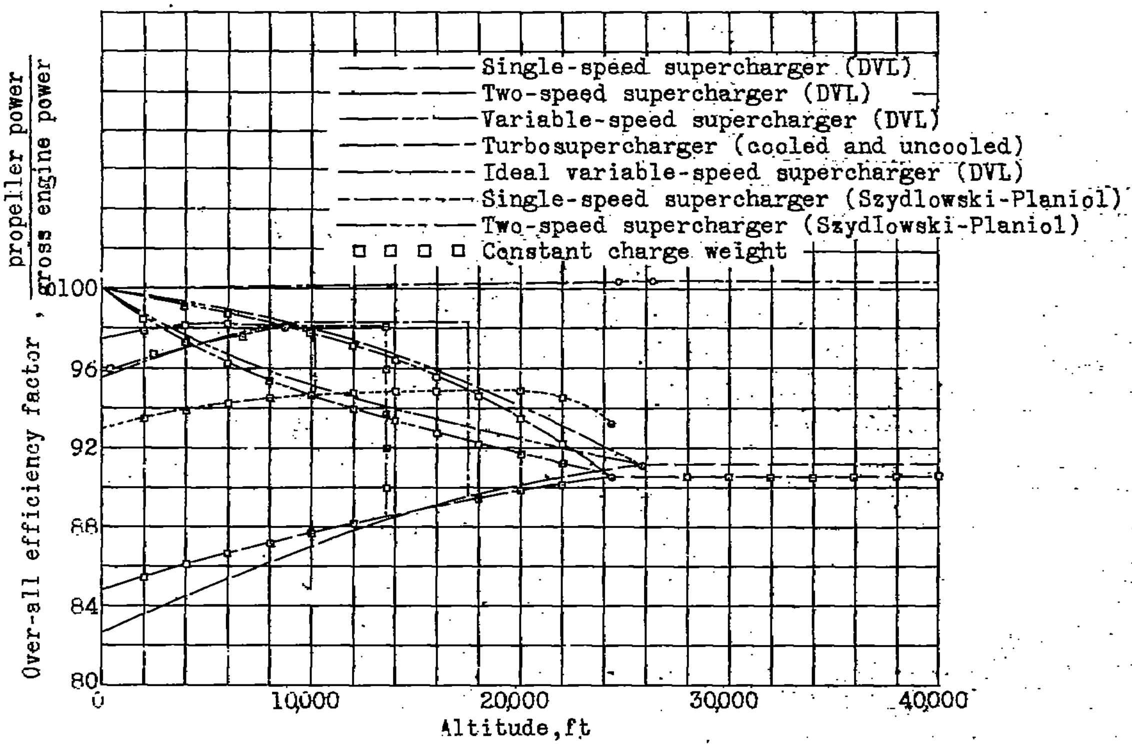

Figure 11.- Over-all efficiency factor for various superchargers. Manifold pressure below critical altitude, 29.92 inches of mercury.

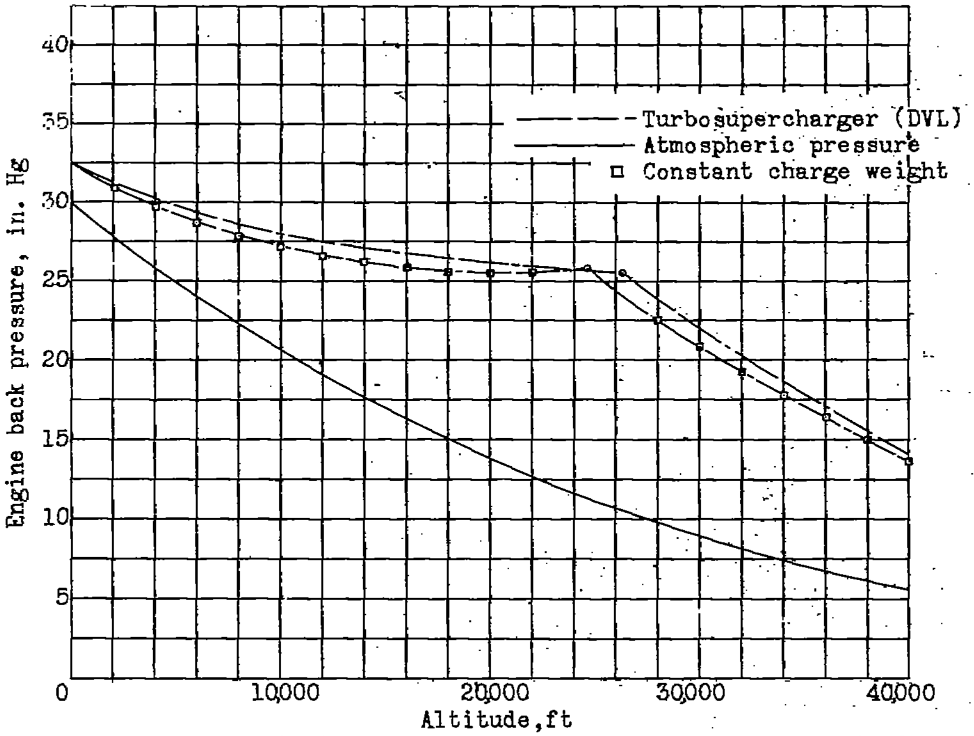

Figure 12.- Engine back pressure for turbosupercharger. Manifold pressure below critical altitude, 29.92 inches of mercury.

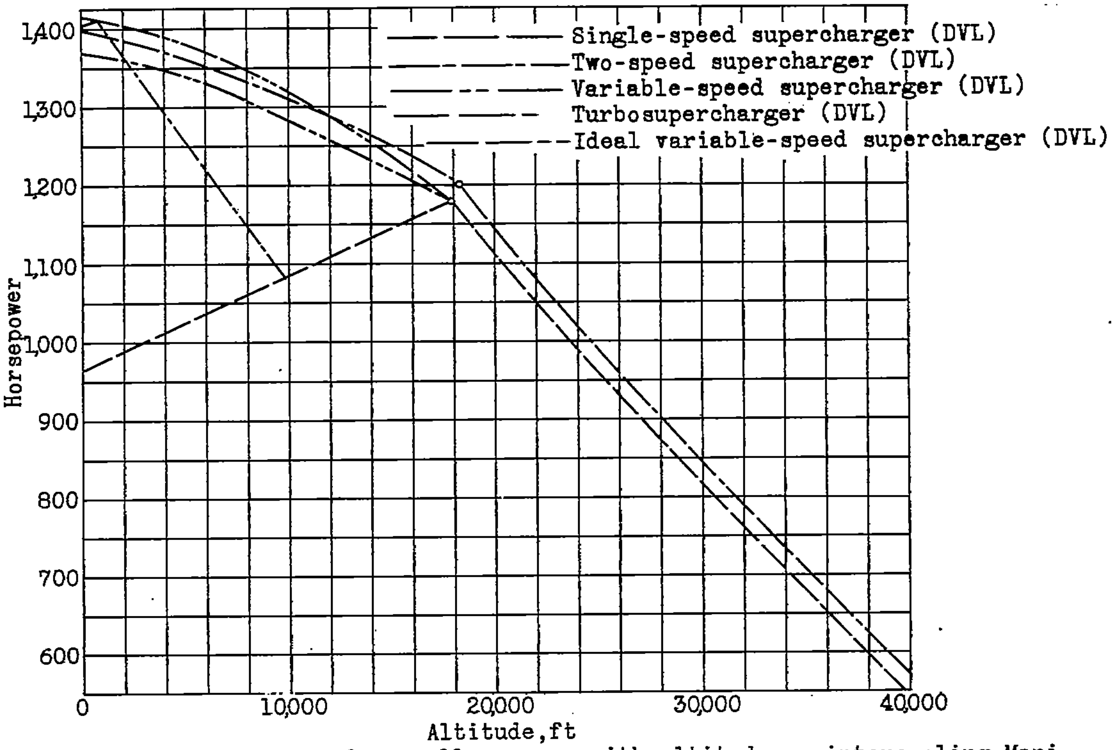

Figure 13.- Variation of propeller power with altitude,no intercooling.Manifold pressure below critical altitude,40 inches of mercury.

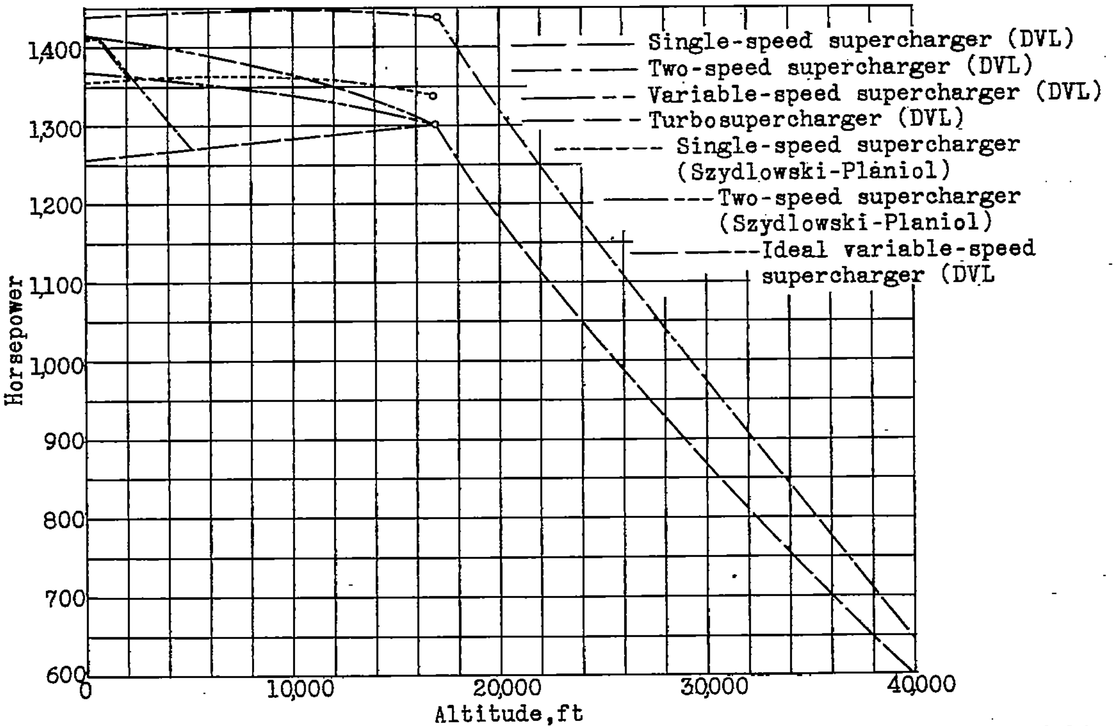

Figure 14.- Variation of propeller power with altitude,constant charge weight. Manifold pressure below critical altitude,40 inches of mercury.

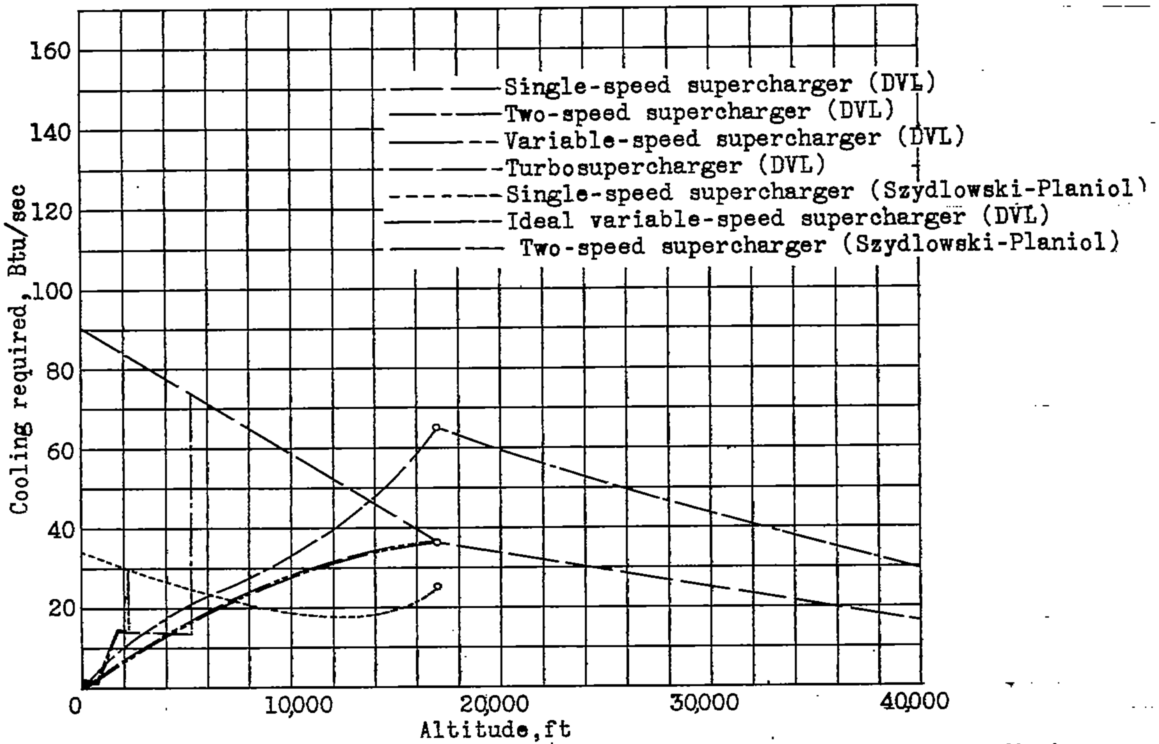

Figure 15.- Amount of intercooling required for various superchargers.Manifold pressure below critical altitude,40 inches of mercury.

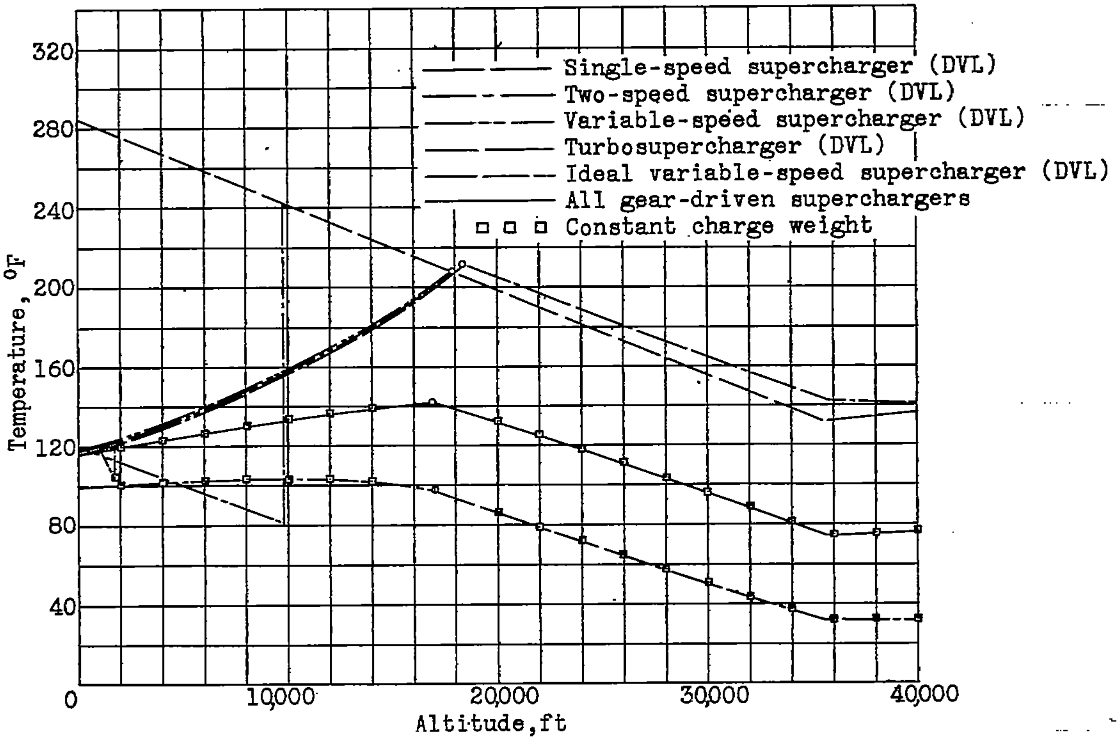

Figure 16.- Manifold temperature for various superchargers. Manifold pressure below critical altitude,40 inches of mercury.

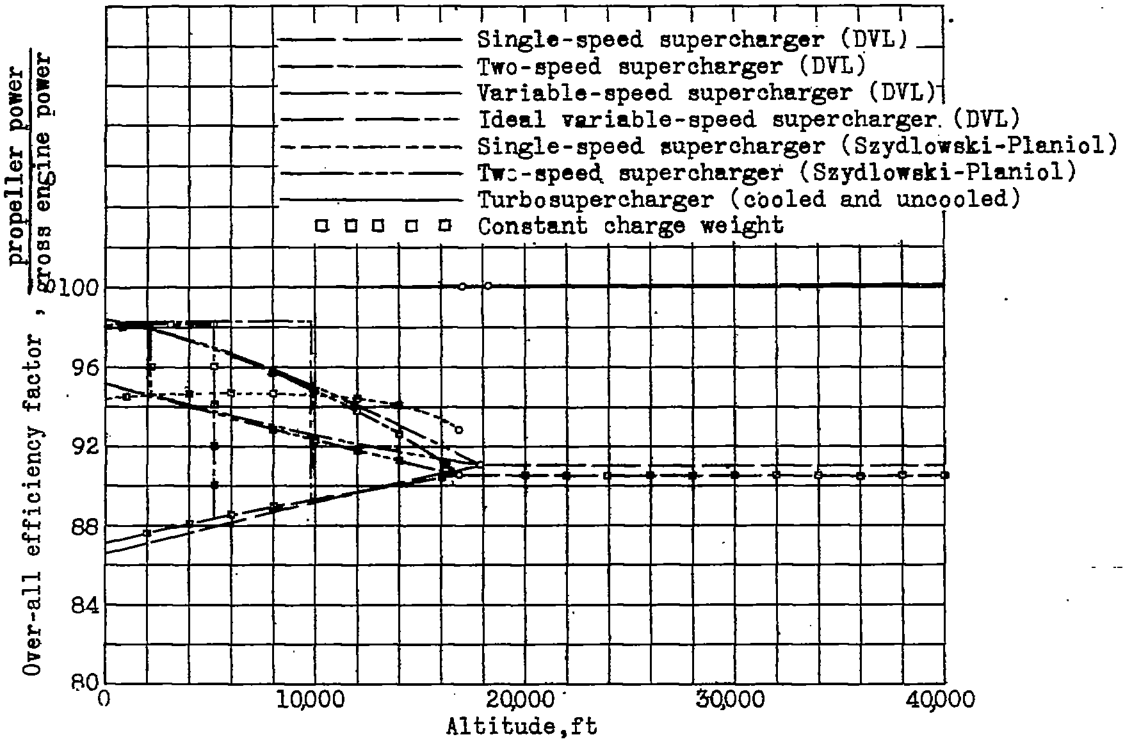

Figure 17.- Over-all efficiency factor for various superchargers. Manifold pressure below critical altitude, 40 inches of mercury.

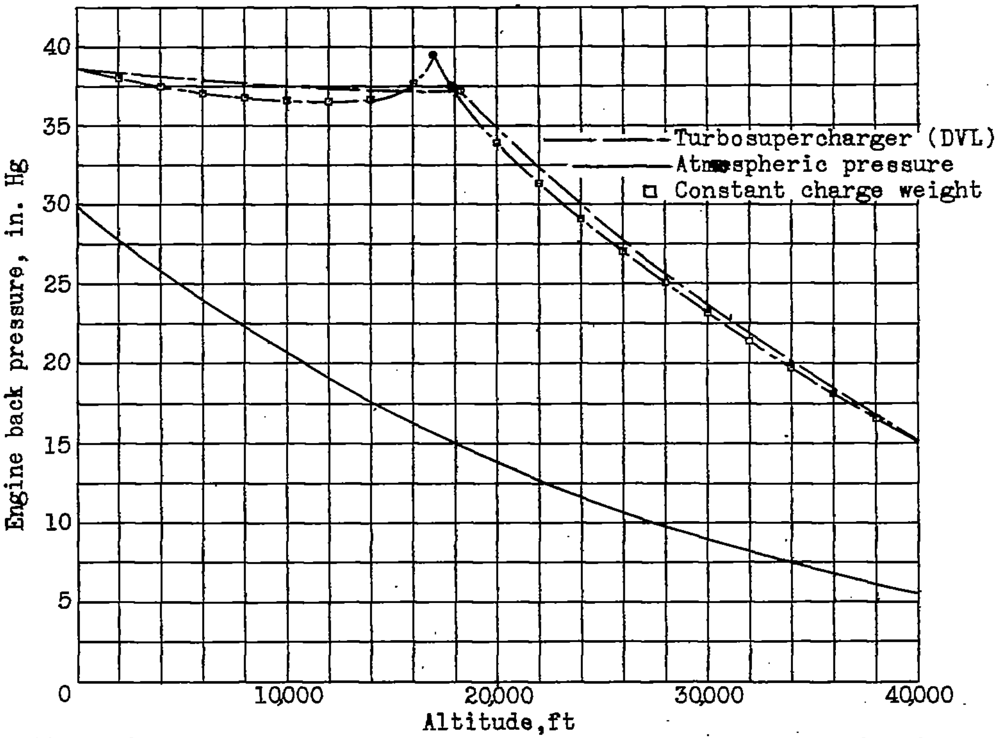

Figure 18.- Engine back pressure for turbosupercharger. Manifold pressure below critical altitude, 40 inches of mercury.