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The Increase in Thrust Obtainable from a Power Plant Installation using the Cooling-air as a Propulsive Jet

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F/Lt. A. B. P. Beeton

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The Increase in Thrust Obtainable from a Power Plant Installation using the Cooling-air as a Propulsive Jet

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Summary.—The net thrust or drag of a power-plant cooling system has been estimated for various flight speeds. The effect of using the exhaust heat inside the duct is considered, and also the effect of burning additional fuel behind the engine. Typical figures are taken to produce a set of curves, from which the respective merits of the various systems considered can be assessed in a general manner. It is concluded that useful gains in total thrust might be obtained at top speed by the use of internally discharging exhausts. The gain from auxiliary fuel burners behind the engine would only be considerable at very high speeds.

1. *Introduction.*—1.1. The air used in the cooling system of an aircraft power-plant may be considered as the working fluid of a thermodynamic cycle. In the ideal case, it is first brought to rest adiabatically in front of the engine, with a consequent rise in pressure. Heat is then added from the body to be cooled, and the air is expelled rearwards at a final pressure equal to that of the atmosphere. The efficiency of conversion of heat into kinetic energy would be $\frac{\gamma - 1}{\gamma} \cdot \frac{\delta P}{P}$ is the ideal cycle, where $(\delta P/P)$ = relative pressure rise due to flight speed, and is a small quantity. This is also the theoretical overall efficiency for a small heat input per unit mass-flow, when the Froude propulsive efficiency is 100 per cent.

1.2. At 400 m.p.h. at high altitude, the quantity $(\delta P/P)$ is $0 \cdot 258$, and the efficiency even in this case is only $7 \cdot 4$ per cent. as given by the above approximate formula. At lower speeds it will be very much less. The conversion of heat into mechanical energy by this process is therefore very inefficient, and although the quantity of heat available may be considerable, the available horse-power for propulsion will in most cases be insignificant.

1.3. In an actual installation, there is also a pressure drop over the engine to be accounted for, and the compression and expansion processes are not carried out entirely without loss. These factors will introduce more drag in most cases than can be offset by the ideal thermodynamic net increase in thrust due to heating.

1.4. Simple equations from which the resultant thrust or drag can be calculated are given in the Appendix. This has been done over a range of flight speeds for the following conditions :—

(*a*) Engine cold.

(*b*) Air temperature rise over engine 50 deg. C. This is the maximum likely to be obtained with the conventional air-cooled engine system.

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(*c*) 250 deg. C. corresponding temperature rise. This can be taken as a typical value for the case when the exhaust heat is added to the cooling air. The whole of the fuel heat not converted into propeller horse-power is thus being put into the cooling air stream.

(*d*) 750 deg. C. temperature rise. This would mean the duct running almost at red heat, and is probably near the top limit on this account. The additional heat required would have to be supplied by auxiliary burners behind the engine.

1.5. The results obtained from these calculations should be fairly typical, but in any given case it will be realised that different constants may apply, and the absolute values for the thrusts given may vary considerably.

1.6. The possibility of using a fan in front of the engine to increase the pressure at low flight speeds has not in this case been considered.

2. *Summary of Results.*—2.1. Using the formulae given in the Appendix, constants were taken as below :—

$$\gamma = 1\cdot400 \text{ (therefore } k = \sqrt{(2gJ\cdot K_p)} = 147\cdot2).$$

$T_0 = 250$ deg. C. Abs. ; temperature of cooling air.

Intake duct efficiency $\eta = 0\cdot80$. Outlet duct efficiency $\eta' = 0\cdot875$.

Engine pressure drop constant $\lambda_m{}^2 T_0/P_0{}^2 = 0\cdot020$.

This is a typical figure for an air cooled radial engine at 10,000 ft. altitude.

2.2. The various cases given in Sect. 1.4 were considered by putting $(T_2 - T_1) = 0$, 50, 250 and 750 deg. C. The results are plotted against flight speed in Fig. 2, together with the intake momentum drag. The net thrust or drag is then the difference between this line and the calculated curves for gross thrust.

2.3. To compare the relative values of the net thrust or drag in the different cases, and also to give an idea of the magnitude of this quantity, it is plotted in Fig. 3 as a fraction of the propeller thrust horse-power. The following assumptions are made :—

Propeller efficiency $= 0\cdot75$.

Engine mechanical efficiency $= 0\cdot85$. $(= 1 -$ (Blower h.p. + f.h.p.)/i.h.p.).

Cooling-air mass-flow $= 8 \times$ engine air consumption.

Engine indicated power $= 10\cdot4$ i.h.p./lb. air/min.

Therefore propeller thrust power $= 0\cdot75 \;.\; 0\cdot85 \;.\; 10\cdot4 \;.\; 60/8$, or in round figures $50\cdot0$ i.h.p. per lb./sec. flowing in the ducted cooling system.

Therefore, if $\Delta\theta$ is the net thrust given in Fig. 2 for flight speed v_0 ft./sec.,

$$\text{h.p. in duct/Prop. t.h.p.} = (\Delta\theta \;.\; v_0/550 \;.\; 50) \;.\; 100 \text{ per cent.}$$
$$= 0\cdot00364\Delta\theta \;.\; v_0 \text{ per cent.}$$

2.4. To show the order of the effect of assuming different efficiency factors η and η' in the engine intake and expansion ducts respectively, a further set of curves is given in Fig. 4, for which both of these quantities have been taken as 100 per cent. The same cooling pressure-drop constant has however been retained.

2.5. It will be realised that the heating effect only of the exhaust gases has been taken into account. The thrust derived from the momentum of the gases may be considerable if the exhaust system is suitably designed. This momentum will still appear as thrust even when the internally-mixed system is used (case (*c*) above), and may even be increased under suitable conditions by applying the principle of the " augmenter ". The exhaust thrusts for the various cases have therefore been taken as the same, and have accordingly been left out of the calculations, which are only concerned with relative values.

3. *Conclusions.*—3.1. The following general conclusions may be drawn from a study of Figs. 2 and 3 :—

3.2. With the usual air-cooled engine arrangement, allowing for intake momentum drag, a net loss in the cooling air duct of the order of 5 per cent. of the propeller thrust horse-power occurs, varying only slightly with flight speed.

3.3. The use of the exhaust heat inside the duct may show a gain of about 10 per cent. of propeller thrust at 400 m.p.h. This gain may be increased by the possible augmentation of the exhaust momentum when used internally, and by the reduction of aerodynamic drag on the exhaust-pipes.

3.4. The duct burning auxiliary fuel after the engine can be expected to give an increase of the order of 25 per cent. on propeller thrust power at 400 m.p.h. over the conventional cooling duct. This is quite a useful increase in thrust at high speed, and the extra duct and fuel weight needed in this case might be permitted in an aircraft in which a short period of high-speed combat flying is required. No useful gain can, however, be expected under take-off conditions.

3.5. Comparison of Figs. 3 and 4 shows the possible errors involved in the duct efficiency assumptions. If no losses other than the engine pressure drop are assumed in the internal flow, the net thrusts become 2, 14 and 35 per cent. of the propeller thrust with respectively 50, 250 and 750 deg. C. temperature rise. These two sets of curves show the probable limits between which the actual figures would be.

APPENDIX

Equations used in Deriving Values for Duct Thrust

The symbols and suffixes used in these equations are shown in a diagrammatic sketch of the system under consideration (Fig. 1).

Assuming that the air velocity is small in front of the engine, and the ramming efficiency is given by η, then we have

$$T_1 = T_0 + (v_0/k)^2 , \qquad (1)$$

where $k^2 = 2gJK_p$

and $$(P_1/P_0) = (T_1/T_0)^{[\gamma/(\gamma-1)]\eta} . \qquad (2)$$

The pressure drop across the engine can be expressed in the form of an aerodynamic drag coefficient to a first approximation as follows :—

$P_1 - P_2 = C_D \cdot \frac{1}{2}\rho v^2 \times$ (Power plant frontal area), or more conveniently as

$$P_1 - P_2 = \lambda \cdot m^2 T_1/P_1 , \qquad (3)$$

where m lb./sec. is the cooling air mass-flow.

Assuming an expansion efficiency of η', we have the further relations

$$T_2 = T_3 + (v_3/k)^2 \qquad (4)$$

and $$(P_2/P_0) = (T_2/T_3)^{[\gamma/(\gamma-1)]\,(1/\eta')} . \qquad (5)$$

These equations enable the gross duct thrust (v_3/g) lb./lb./sec. to be calculated, if suitable values are taken for T_0, $(T_2 - T_1)$, λ and the component efficiencies. The net thrust is the difference between this and the intake momentum drag, which is given by (v_0/g).

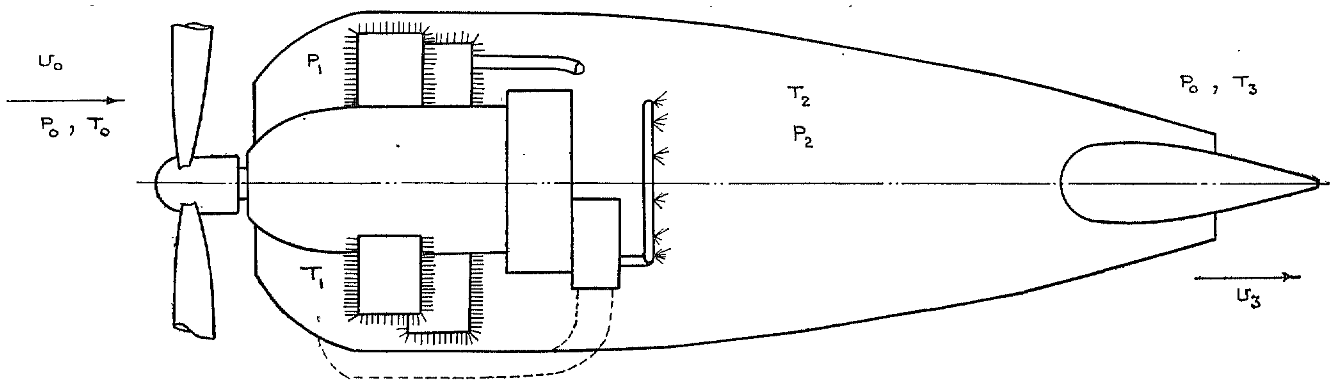

FIG. 1.—Diagrammatic Scheme of Ducted Cooling Air System
(Not to scale)

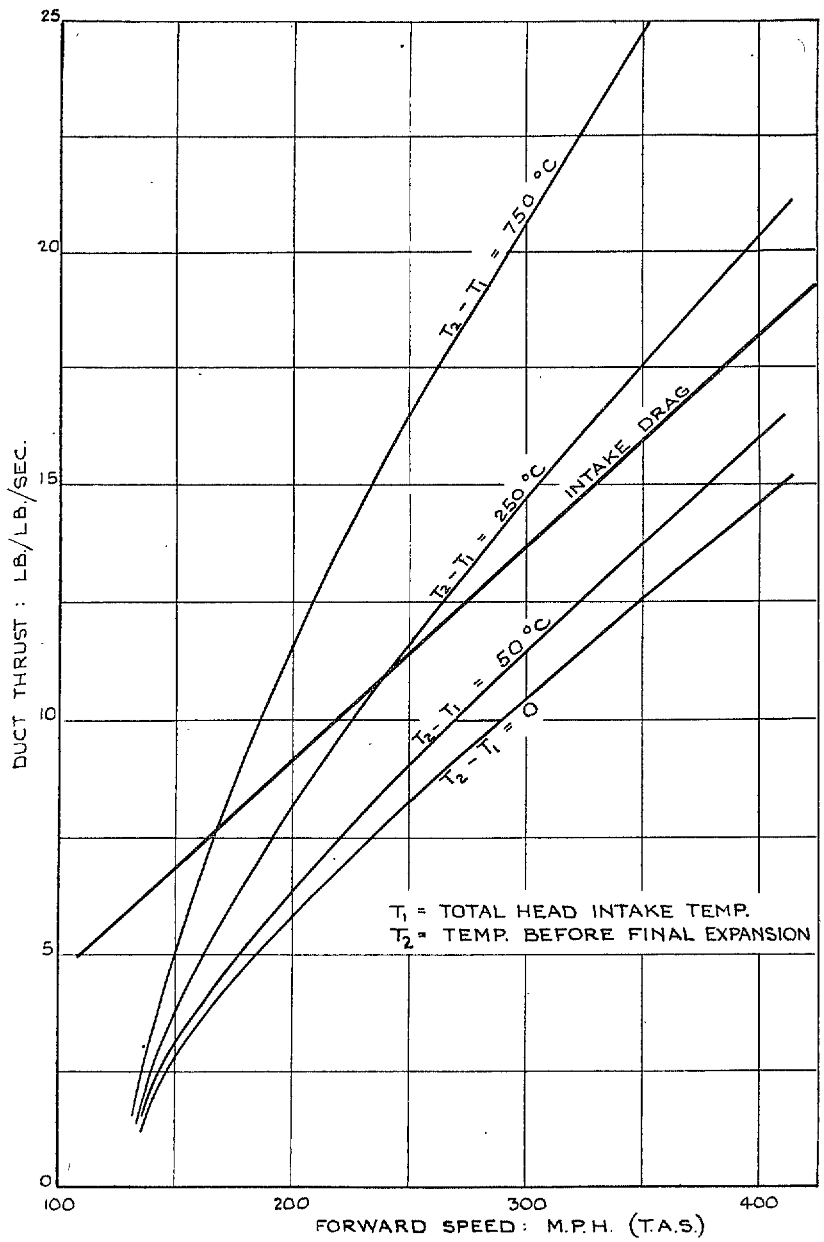

FIG. 2.—Duct Thrusts obtainable for Different Degrees of Heating

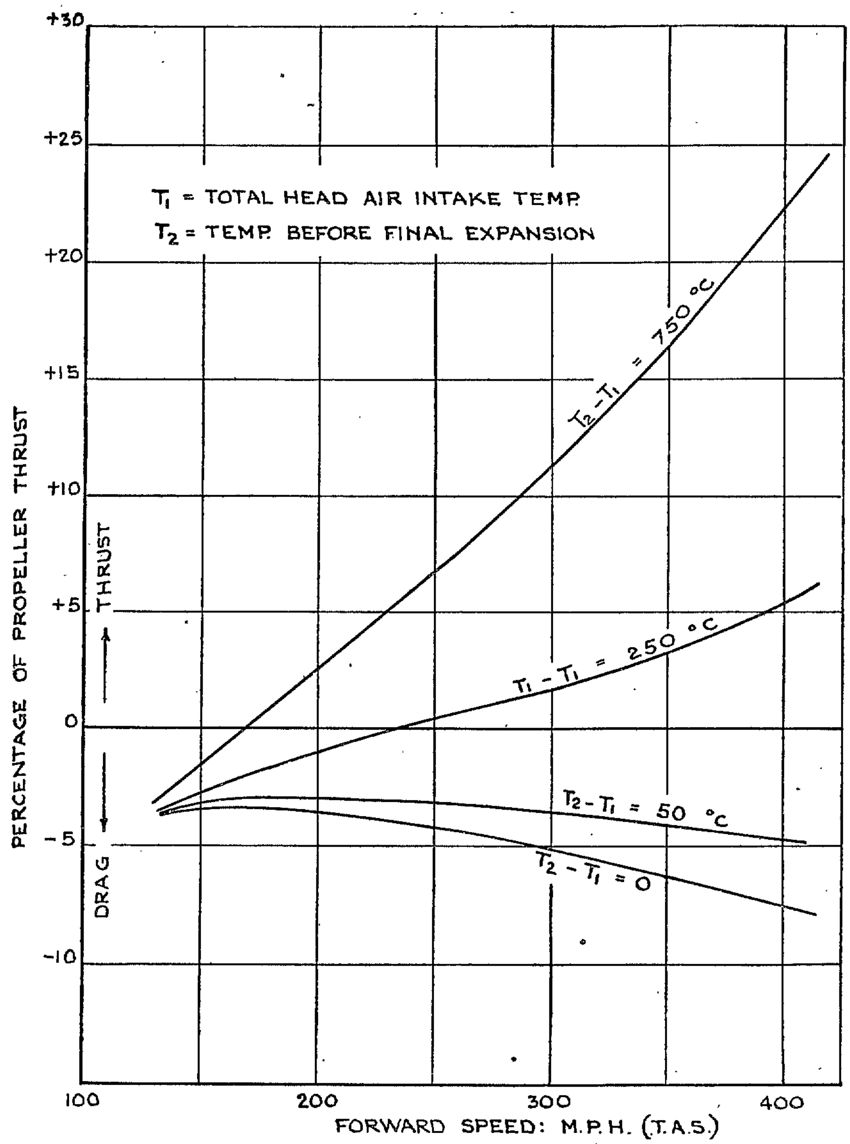

FIG. 3.—Net Thrust or Drag as Percentage of Prop. Power

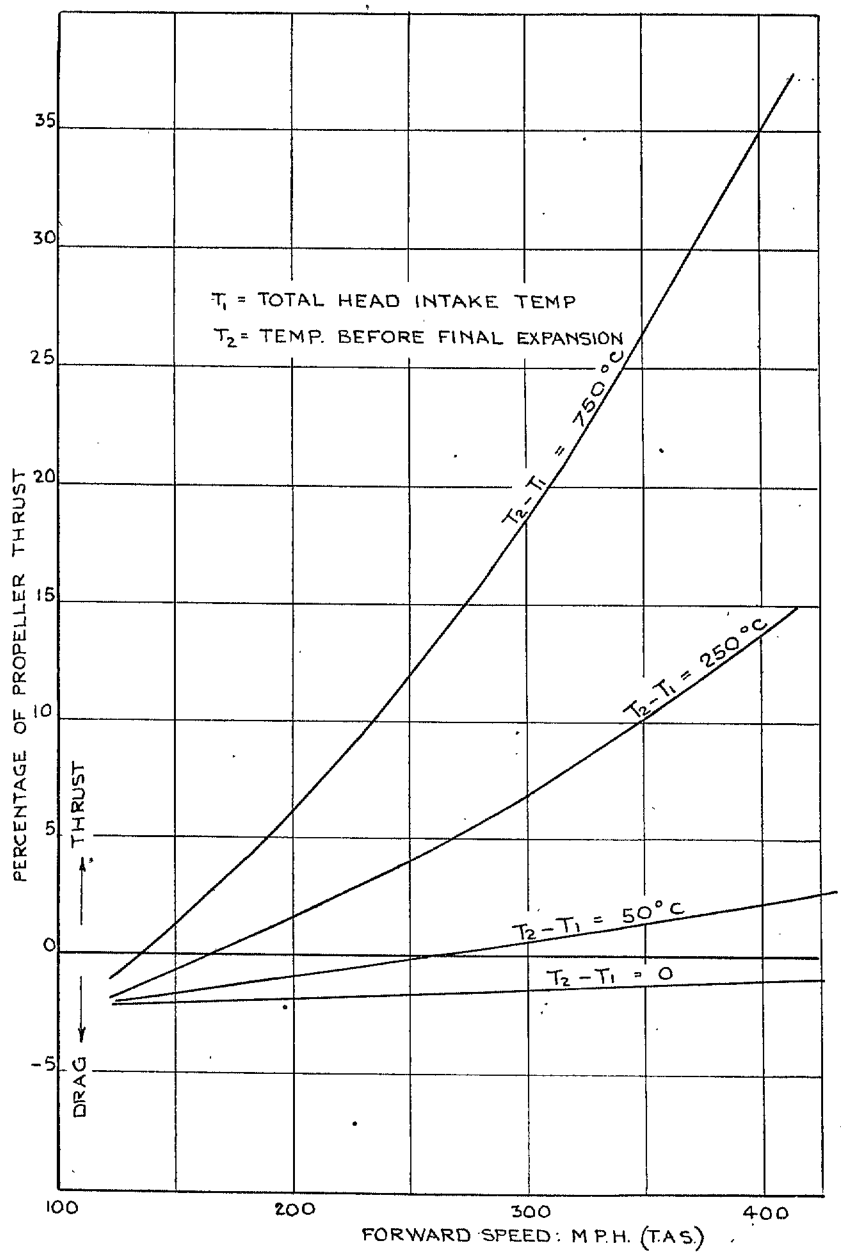

FIG. 4.—Net Thrust or Drag Calculated for 100 per cent. Duct Efficiency

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