NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
March 1945 as
Memorandum Report L5C12b

AN ESTIMATE OF THE EFFECT OF ENGINE SUPERCHARGING ON THE TAKE-OFF THRUST OF A TYPICAL HELICOPTER AT DIFFERENT ALTITUDES AND TEMPERATURES

TED No. NACA 1301

By F. J. Bailey, Jr., and T. J. Voglewede

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

MR No. L5C12b

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

and the

Bureau of Aeronautics, Navy Department

AN ESTIMATE OF THE EFFECT OF ENGINE SUPERCHARGING ON THE TAKE-OFF THRUST OF A TYPICAL HELICOPTER AT DIFFERENT ALTITUDES AND TEMPERATURES

TED No. NACA 1301

By F. J. Bailey, Jr. and T. J. Voglewede

L-592

SUMMARY

Calculations for a typical helicopter indicate that incorporation of a small amount of supercharging should substantially increase its take-off thrust and useful load for a wide range of airport altitudes and air temperatures.

INTRODUCTION

As in the case of the airplane, the helicopter can cruise at powers well below those required for safe take-off in moderate or low-wind conditions. It has been suggested, therefore, that the failure of helicopter and helicopter engine designers to take advantage of the temporary increases in power made possible by modern engine developments in superchargers and high-octane fuels may be limiting the usefulness of the helicopter. As a first step in examining the correctness of this suggestion a brief theoretical study was made of the increases in take-off thrust that would be made possible at different times of the year in various parts of the country by incorporation of a small amount of supercharging in a typical helicopter. The results of this study are given in the present paper.

SYMBOLS

For convenience the symbols used in the analysis are defined in the following list:

bhp	brake horsepower
ihp	indicated horsepower
shp	supercharger horsepower
fhp	friction horsepower
p_m	manifold pressure, inches of mercury
p_o	atmospheric pressure, inches of mercury
Δp	pressure drop from inlet to manifold (or to supercharger entrance for supercharged engine), inches of mercury
r_s	pressure ratio across supercharger
r	cylinder compression ratio
σ	free-air density ratio
W_a	charge air flow, pounds per second
T_m	dry manifold temperature, $^{\circ}F$ absolute
T_o	free-air temperature, $^{\circ}F$ absolute
ΔT	temperature rise across supercharger, $^{\circ}F$
η	supercharger adiabatic efficiency
J	778 foot-pounds per Btu
c_p	specific heat of air at constant pressure (=0.24)
γ	specific heat ratio for air (=1.40)
N_c	number of cylinders
D_c	cylinder diameter, inches

L-592

S	piston stroke, inches
N	engine speed, rpm
C_T	rotor thrust coefficient $= \frac{T}{\pi R^2 \rho (\Omega R)^2}$
C_Q	rotor torque coefficient $= \frac{Q}{\pi R^3 \rho (\Omega R)^2}$
T	rotor thrust, pounds
Q	rotor torque, pound-feet
Ω	rotor speed, radians per second
R	rotor radius, feet
ρ	free-air density, slugs per foot^3
δ	blade element profile-drag coefficient
α	blade element angle of attack, radians

METHOD OF ANALYSIS

Performance of unsupercharged engine.- A typical unsupercharged helicopter engine was selected. This engine was assumed to have the following characteristics at its rated power for continuous full-throttle operation under standard sea-level conditions.

N_c	7
D_c	4.875 inches
S	4.25 inches
r	6.4
N	2100 rpm
p_m	28.7 inches of mercury (Δp = (29.92 - 28.7) = 1.22 inches of mercury)
ihp	200

$fhp = 15 \times 10^{-10} N_c (D_c SN)^2 = 20$ (reference 1)

$bhp = ihp - fhp = 180$

The brake horsepower delivered by this engine at full throttle at 2100 rpm over a range of temperatures from -40° to 120° F and a range of pressure altitudes from 0 to 6000 feet was calculated on the assumption that

$$ihp \propto \left(p_m - \frac{p_o}{r}\right) T_m^{-0.58}$$ (references 1 and 2)

$$p_m = p_o - \Delta p$$

$$\Delta p \propto \frac{W_a^2}{\sigma} \propto \frac{(ihp)^2}{\sigma}$$

Performance of supercharged engine.- The engine was then assumed to be fitted with a single-stage single-speed gear-driven supercharger designed for a pressure ratio sufficient to give 230 indicated horsepower at 2100 rpm at 2600 feet altitude at full throttle on a standard day. The value of 230 for the maximum permissible indicated horsepower represents an increase of 15 percent over that for continuous operation at standard sea-level conditions. This value was selected after study of a number of supercharged engines indicated that temporary increases in indicated mean effective pressure permitted for military or take-off operation ranged from 10 to 20 percent. It also corresponds to the indicated horsepower of the unsupercharged engine in full-throttle operation at sea level at a temperature of -55° F.

Under the design conditions the pressure ratio required was 1.3 which, with an assumed adiabatic efficiency of 75 percent, corresponds to a temperature rise across the supercharger of 53° F and a manifold pressure of 33.2 inches of mercury.

The power delivered by the supercharged engine at full throttle over the range of altitudes and temperatures was then calculated on the assumptions that

$$bhp = ihp - fhp - shp$$

$$ihp \propto \left(p_m - \frac{p_o}{r}\right) T_m^{-0.58}$$

L-592

$$T_m = T_o + \Delta T = T_o + 53^\circ$$

$$p_m = r_s\ (p_o - \Delta p)$$

$$r_s = \left(1 + \eta\frac{\Delta T}{T_o}\right)^{\frac{\gamma}{\gamma-1}} = \left(1 + 0.75\ \frac{53}{T_o}\right)^{3.5}$$

$$\Delta p \propto \frac{(\text{ihp})^2}{\sigma}$$

$$\text{fhp} = 20$$

$$\text{shp} = \frac{W_a J c_p \Delta T}{550}$$

$$= 0.030\ \text{ihp} \quad \text{when} \quad W_a = \frac{6.0 \times \text{ihp}}{3600}$$

It was assumed that the throttle would be used to prevent the indicated horsepower from exceeding the selected maximum permissible value of 230.

Performance of rotor.- The helicopter rotor was assumed to have the following characteristics, which are appropriate for a machine having a gross weight of approximately 2500 pounds:

R, feet	19
Ω, radius per second	23.58
Solidity	0.06
Blade plan form	Constant chord and incidence
c_{d_o}	$0.01 + 0.3\alpha^2$

The relation between rotor static thrust and torque coefficients was derived from figure 15 of reference 3 and is plotted in figure 1. For convenience in the computations the expression

$$C_T = 0.00235\ \left(10^4 C_Q - 0.75\right)^{0.708}$$

was substituted for the curve. The curve may be considered to represent the hovering performance of current rotors with fabric-covered blades.

The rotor thrust was calculated for both the supercharged and unsupercharged conditions over the range of altitudes and temperatures, on the assumption that 80 percent of the engine brake horsepower was delivered to the rotor.

RESULTS AND DISCUSSION

The calculated values of engine brake horsepower for the two conditions are presented in figure 2. The increase in static thrust resulting from the increased brake horsepower of the supercharged engine is shown in figure 3. It is evident that the take-off thrust increases made possible by supercharging are large in relation to the probable weight of the supercharger, particularly when operation is to be from airports above sea level at moderate or summer temperatures. For example, installation of the supercharger would increase the useful load at take-off from a 1000-foot-high airport at 75° F by 350 pounds, or about 70 percent, even when a rather generous allowance of 50 pounds is made for the weight of the supercharger.

CONCLUDING REMARKS

The foregoing calculations indicate that incorporation of supercharged engines in current helicopters may be expected to increase substantially the useful load at take-off from most airports in any but extremely cold weather. The problem of developing suitable supercharged engines for helicopters appears to warrant further consideration.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

ER

L-592

REFERENCES

1. Staff of Engine Dept.: Engine Power at High Altitudes. Rep. No. E3912, British R.A.E., Dec. 1941.

2. Sanders, Newell D., Barnett, Henry C., and Bolz, Ray E.: Effect of Inlet-Air Temperature and Cylinder Displacement on Charge Temperature of Internal-Combustion Engines. NACA RB No. 4A17, 1944.

3. Knight, Montgomery, and Hefner, Ralph A.: Static Thrust Analysis of the Lifting Airscrew. NACA TN No. 626, 1937.

L-592

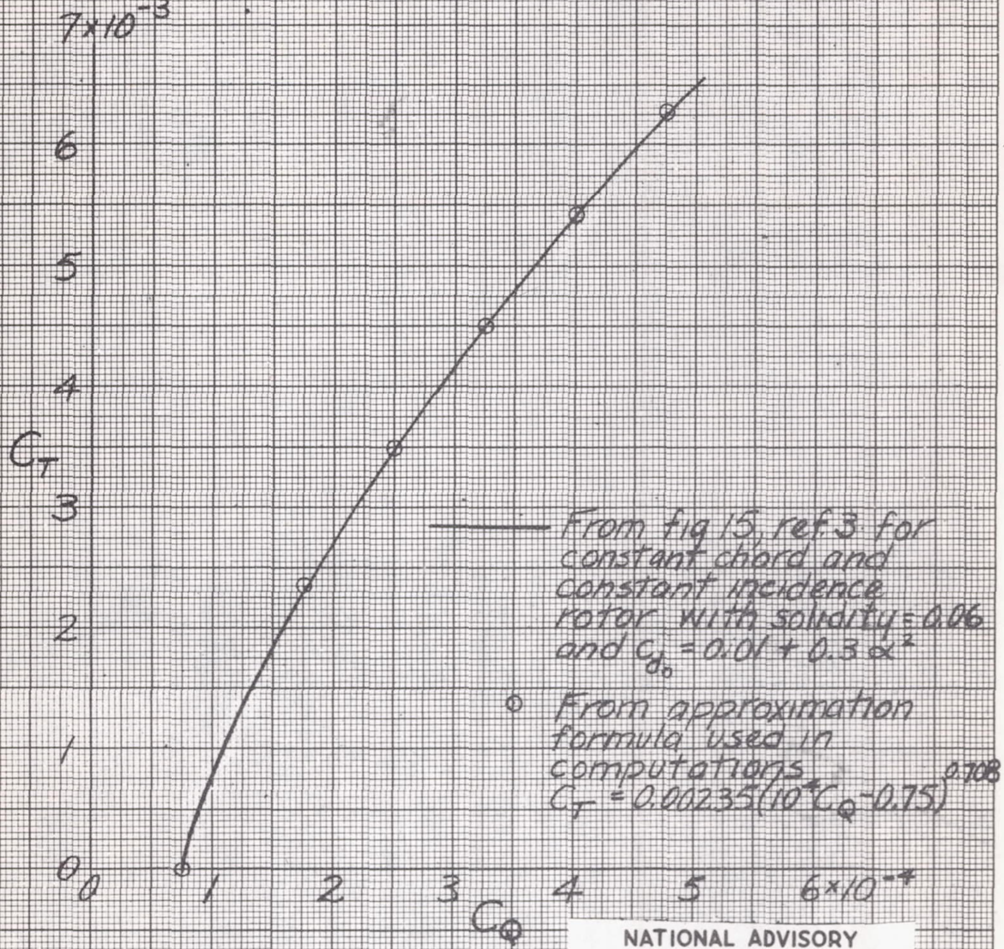

Figure 1.- Relation between thrust and torque coefficients for the assumed rotor.

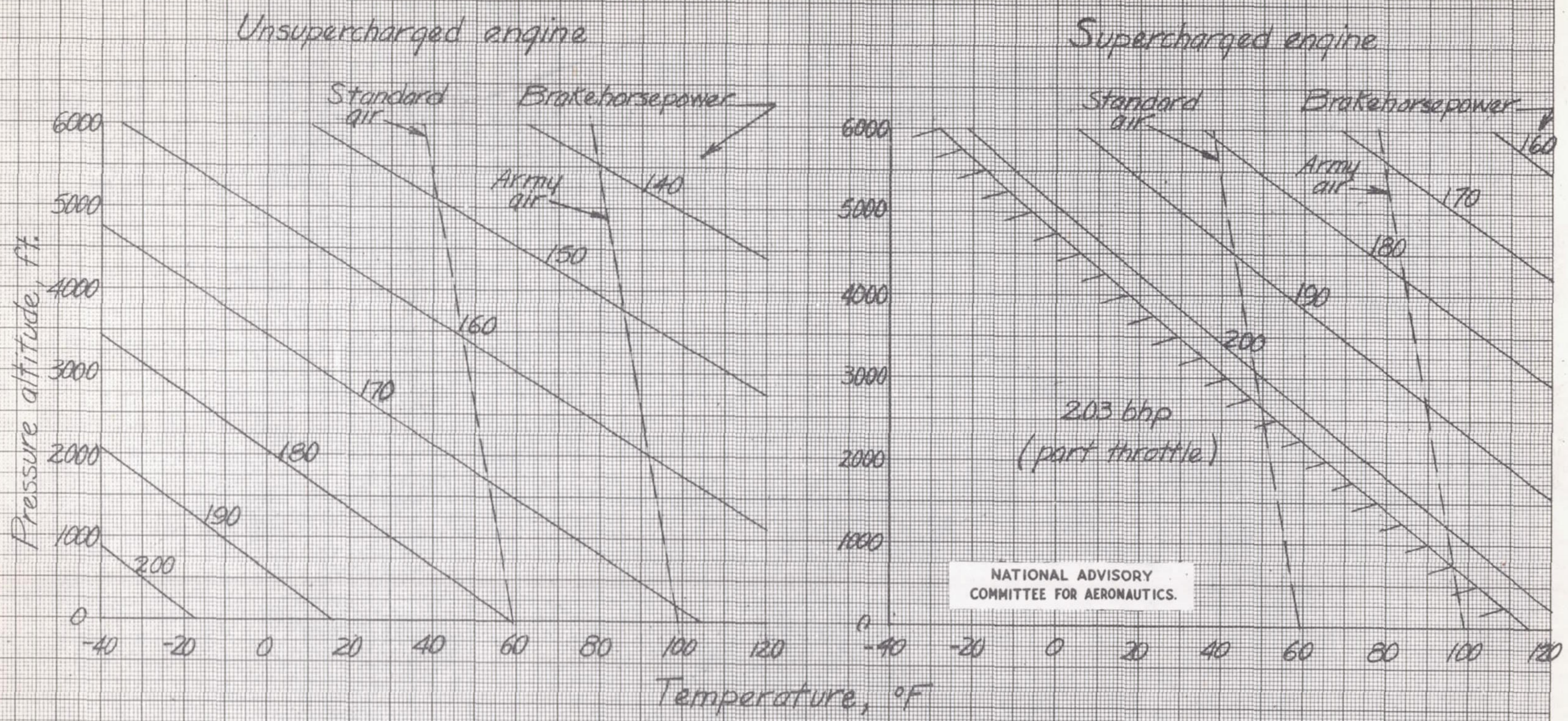

Figure 2.- Full throttle performance of unsupercharged and supercharged engines.

L-592

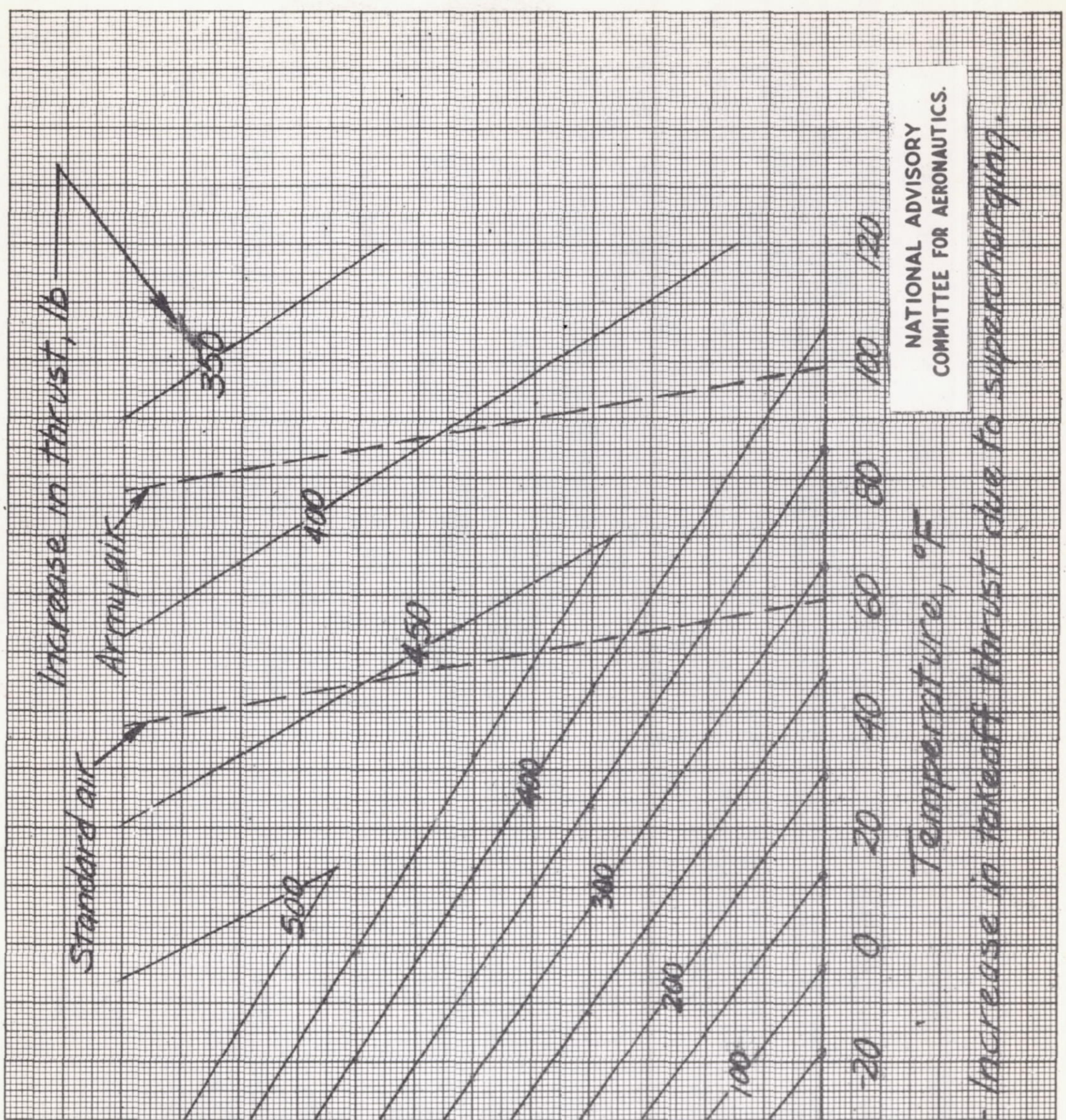

Figure 3.- Increase in takeoff thrust due to supercharging.