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THE EFFECT ON ENGINE PERFORMANCE OF CHANGE IN JACKET-WATER OUTLET TEMPERATURE

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Bureau of Standards

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SUMMARY

Tests made on a Curtiss D-12 engine in the Altitude Laboratory at the Bureau of Standards show the following effects on engine performance of change in jacket-water outlet temperature:

1) Friction at all altitudes is a linear function of jacket-water temperature, decreasing with increasing temperature.

2) The brake horsepower below an altitude of about 9,000 feet decreases, and at higher altitudes increases, with increasing jacket-water temperature.

3) The brake specific fuel consumption tends to decrease, at all altitudes, with increasing jacket-water temperature.

4) The percentage change in brake power output is roughly equal to the algebraic sum of the percentage change in volumetric efficiency and mechanical efficiency.

INTRODUCTION

Valuable information has been obtained by several investigations of the performance of liquid-cooled aircraft engines, with high coolant temperatures. All the dynamometer data, however, have been obtained with engines operating at sea level.

Because of the interest in this subject a brief experimental program has been conducted in the Altitude

Laboratory (references 1 and 2) to determine the effects of change of jacket-coolant temperature at altitudes of 10,000 and 20,000 feet as well as at sea level. This is the only laboratory in this country where it is possible to conduct dynamometer tests of aircraft engines under controlled conditions which precisely reproduce those actually encountered in flight at various altitudes.

The only coolant used was water and the range of available temperatures was therefore limited to that between the coldest obtainable from the city water mains and a maximum of 100° C. The tests were made at but one speed and one compression ratio. Altitudes of 10,000 and 20,000 feet were selected because previous tests with a Liberty engine some years ago had indicated that the power output was invariant with jacket-water temperature at an altitude slightly below 10,000 feet. Since the power output at sea level decreased with increasing jacket-water temperature, it appeared that at higher altitudes the power output might increase with increasing temperature.

APPARATUS AND EQUIPMENT

The engine used was a Curtiss D-12 twelve-cylinder, V-type with a compression ratio of 5.3 : 1, loaned by the Bureau of Aeronautics, Navy Department. The displacement is 1,160 cu. in., and the engine is rated 435 brake horsepower at 2,300 r.p.m. at sea level. All test runs were made at an engine speed of 2,000 r.p.m. at which speed the normal sea-level power was 401 brake horsepower at 77° C. jacket temperature.

The carburetor intake air was held at 15° C., being first dehumidified by cooling to about -40° C. By means of an external oil reservoir the oil inlet temperature was held constant at 60° C. The temperature of the jacket water was controlled by circulating it through a tank to which steam or cold water could be added. The coldest runs were made by passing water from the city mains directly through the engine without recirculating.

Two Stromberg carburetors, type NA-Y5D, with no. 46 main jets were used. The fuel consisted of a mixture of one third benzol and two thirds domestic aviation gasoline. The oil used was Liberty Aero, grade three, possessing a

Saybolt Universal viscosity of 697 seconds at 130° F. (54.4° C.) and 98 seconds at 210° F. (98.9° C.).

All results are based on maximum power values obtained from mixture ratio runs in which the mixture ratio was varied on each side of the optimum until a definite reduction in power was observed. Fuel consumption was determined by timing the flow from a calibrated measuring tank and a venturi which had been calibrated against a Thomas meter was used to measure the air flow to the carburetor. Friction power loss was determined by motoring the engine with the dynamometer.

RESULTS

For the purposes of this report, indicated horsepower is defined as the sum of the measured brake horsepower and the friction horsepower, the latter being the power required to drive the engine when motoring with the dynamometer. Volumetric efficiency is defined as the ratio of the volume of air received per cycle, measured at the temperature and pressure existing at the carburetor entrance, to the piston displacement. Because less heat was absorbed by the jacket water in the friction runs, lower jacket temperatures were possible than when operating under power.

Referring to figure 1, the friction horsepower at all three altitudes decreases approximately linearly with increasing jacket temperature. At an altitude of 20,000 feet the friction horsepower decreases 0.52 percent for each degree increase in jacket-water temperature. At an altitude of 10,000 feet the decrease is 0.50 percent for each degree increase in jacket-water temperature and at sea level 0.39 percent. Frank (reference 3) found that the friction of a Curtiss Conqueror engine operating at sea level was approximately linearly variant with jacket-coolant outlet temperature, the average decrease being 0.33 percent for each degree increase in temperature.

This change in friction horsepower is primarily due to change in the viscosity of the oil. Oils vary widely in their viscosity-temperature relation. Accordingly other oils would affect friction and consequently brake horsepower differently. It seems probable that an oil with a different viscosity-temperature coefficient would give a friction curve of different slope, while an oil of similar viscosity-temperature coefficient but of different Saybolt viscosity at a given temperature would shift the curve parallel to itself.

The brake power decreases with increasing jacket-water temperature at sea level, is nearly constant at 10,000 feet and increases at 20,000 feet. The decrease in brake horsepower at sea level is in accord with the findings of Frank (reference 3) and Nutt (reference 4) for the range covered by the present tests. Figure 2 indicates that jacket temperature has no effect on brake horsepower at an altitude of about 9,000 feet.

The indicated horsepower at all altitudes decreases with increasing jacket water outlet temperature, the percentage decrease for an increase in jacket water temperature from 35° C. to 95° C. being 5.7 percent at sea level, 4.5 percent at 10,000 feet and 5.5 percent at 20,000 feet.

The change of volumetric efficiency and mechanical efficiency with jacket-water temperature at sea level and at altitudes of 10,000 and 20,000 feet is shown in figure 3. Volumetric efficiency decreases with increasing jacket-water temperature because the increased warming in the jacketed intake manifolds and cylinders decreases the charge weight inducted. The increase in mechanical efficiency results from the more rapid decrease of friction than of indicated power with increasing jacket temperature. The percentage change in brake horsepower is approximately equal to the net change in the volumetric and mechanical efficiencies. This is in accord with Ricardo's view (reference 5, page 86) that the change in power is due to the variation in volumetric efficiency and friction, and only negligibly to change in heat loss from the ignited charge to the jacket with variation in jacket temperature.

Referring to figure 3, at sea level, the increase in mechanical efficiency is 1.3 percent for the range of jacket-coolant temperature 69.5° C. (157° F.) to 100° C. (212° F.), whereas Frank (reference 3) with a Curtiss Conqueror engine noted an increase of only 0.5 percent.

The tendency at all altitudes is for the brake specific fuel consumption to decrease with increasing jacket-water temperature. This tendency is due largely to the increase in mechanical efficiency with increasing jacket-water temperature, and to better vaporization of the fuel due to the warming up of the intake manifolds (figure 3). Nutt (reference 4) using a Curtiss Conqueror engine varied the jacket-coolant temperature from 86° C. to 149° C. He found that the brake specific fuel consumption decreased gradually until the temperature reached 121° C. and then increased. For a given engine the temperature at which this reversal occurred would doubtless be a function of the oil characteristics. Frank (reference 3) found for the same engine an average decrease in brake specific fuel consumption of 0.22 percent per degree Centigrade increase in jacket-coolant temperature. This is the same percentage change as shown in figure 3. However, the plotted results were obtained with the Curtiss D-12 engine under maximum power conditions at 2,000 r.p.m., whereas Frank's results were obtained with the Curtiss Conqueror engine operating at $99\frac{1}{2}$ percent of maximum power and a speed of 2,100 r.p.m. With a Curtiss D-12 engine, Frank (reference 3) reported an increase in brake specific fuel consumption with increasing jacket-coolant temperature when running full rich at 2,000 r.p.m., and a decrease when operating on the lean side of maximum power. The mechanical efficiency decreases with altitude, accounting for the increase in specific fuel consumption with increase in altitude.

At sea level the falling off in brake horsepower with increasing jacket temperature, partly offsets the advantage gained due to the decrease in specific fuel consumption. For the range covered, the decrease in brake specific fuel consumption is 13.7 percent, whereas the decrease in brake power is only 3.4 percent. In the case of aircraft engines this decrease in specific fuel consumption may be a great advantage and more than offset the disadvantage of the decrease in power output.

In analyzing the distribution of the available heat in the fuel and in computing thermal efficiency, a value of 19,600 B.t.u. per pound was assumed. Since the exhaust gases were cooled by injecting water into them (reference 1) the higher heating value of the fuel has been chosen. In figure 4 the percentage of fuel heat appearing as useful work is seen to increase linearly with increasing jacket-water temperature at all altitudes. The percentage of fuel heat carried away by the jacket water decreases with increasing temperature at all altitudes because of increasing radiation and convection from the engine.

Friction horsepower has been plotted as percentage of heat in the fuel. While a part of the friction no doubt appears as heat in the jacket water, no difference was detected in intake and outlet jacket-water temperatures when taking friction power readings. The amount of water circulated through the jacket was about 300 kilograms per minute and the temperature readings are probably accurate to within $\pm\frac{1}{2}$° C.

It is evident that the greater part of the friction is accounted for as heat lost in radiation and convection, pumping losses and power required to drive the gears, pumps and accessories.

CONCLUSIONS

In view of the large changes in specific fuel consumption and friction with change of jacket-water temperature, it would seem that the subject deserves further attention. The questions of speed, independent control of intake-manifold temperature, and compression ratio should be studied. The range of altitude pressures and jacket-coolant temperatures should be increased and tests should be conducted varying the carburetor intake-air temperature with altitude according to the standard atmosphere. It might also be well to conduct the tests with various lubricating oils and jacket coolants.

Bureau of Standards,
Washington, D. C., Oct. 18, 1933.

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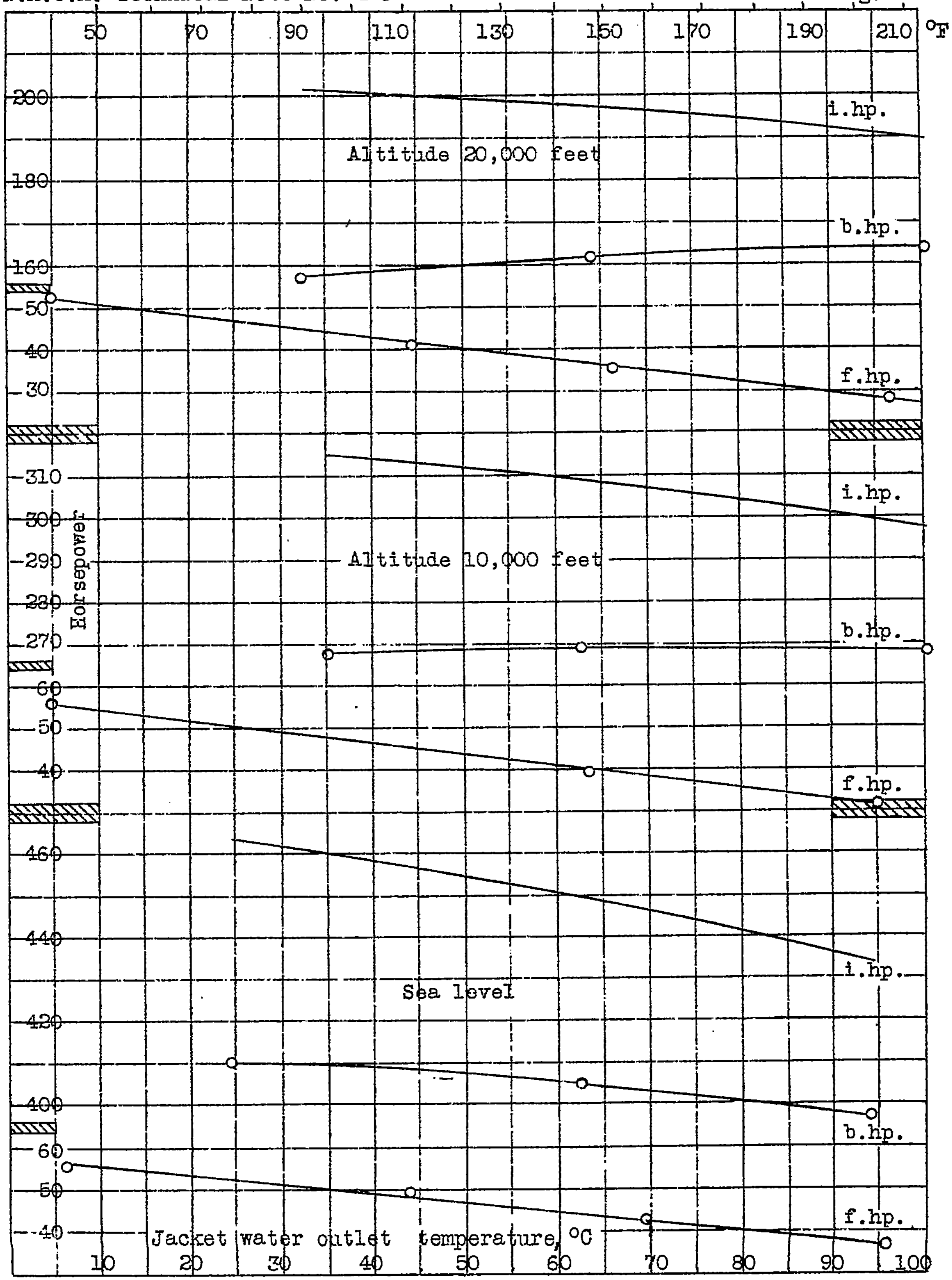
50
70
90
110
130
150
170
190
210
°F
200
180
160
50
40
30
i.hp.
Altitude 20,000 feet
b.hp.
f.hp.
310
300
290
280
270
60
50
40
Horsepower
i.hp.
Altitude 10,000 feet
b.hp.
f.hp.
460
440
420
400
60
50
40
i.hp.
Sea level
b.hp.
f.hp.
Jacket water outlet temperature, °C
10
20
30
40
50
60
70
80
90
100

Figure 1.

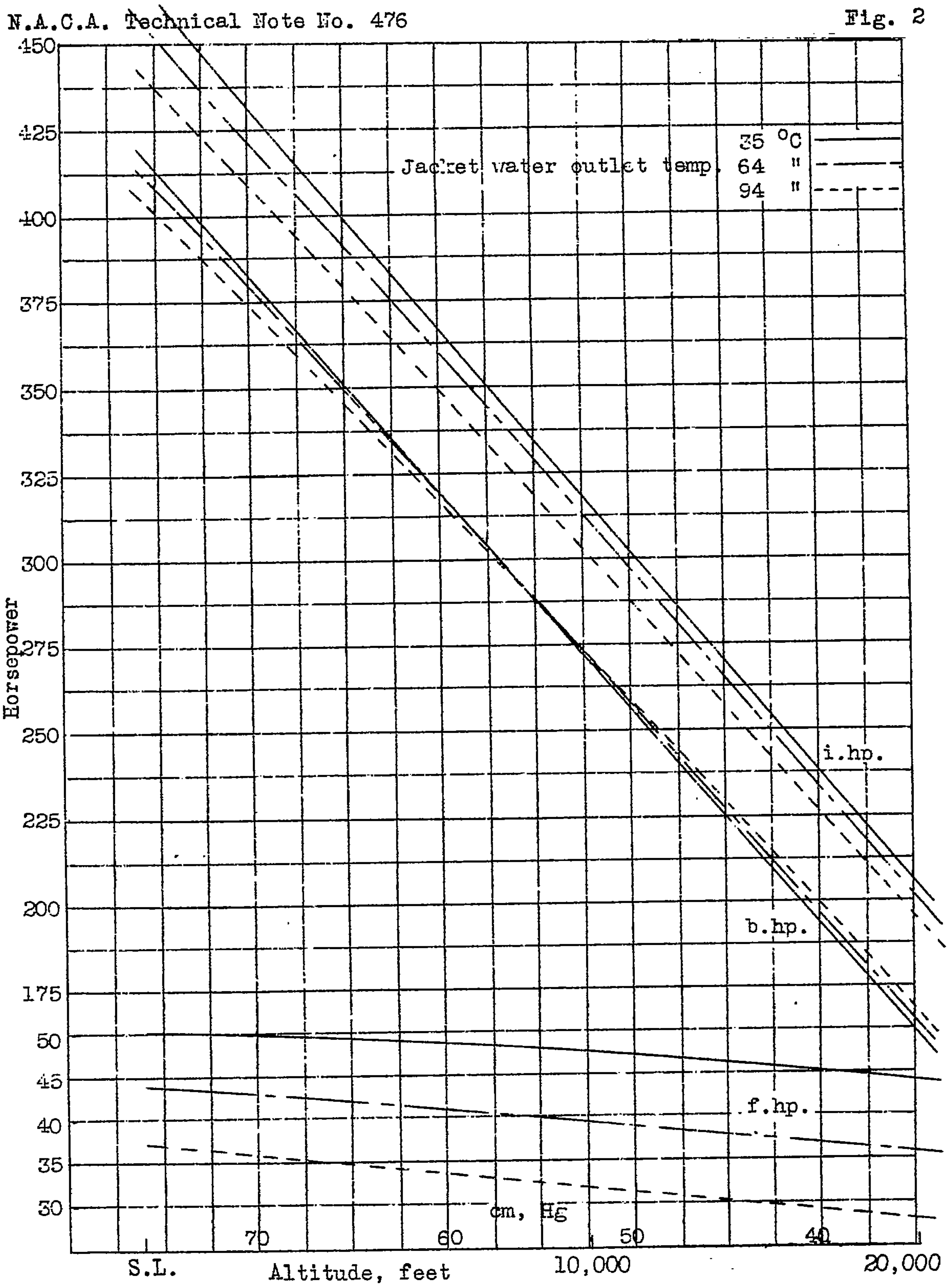
450
425
400
375
350
325
300
275
250
225
200
175
50
45
40
35
30
Horsepower
Jacket water outlet temp. 35 °C
64 "
94 "
i.hp.
b.hp.
f.hp.
cm, Hg
70
60
50
40
S.L.
Altitude, feet
10,000
20,000

Figure 2.

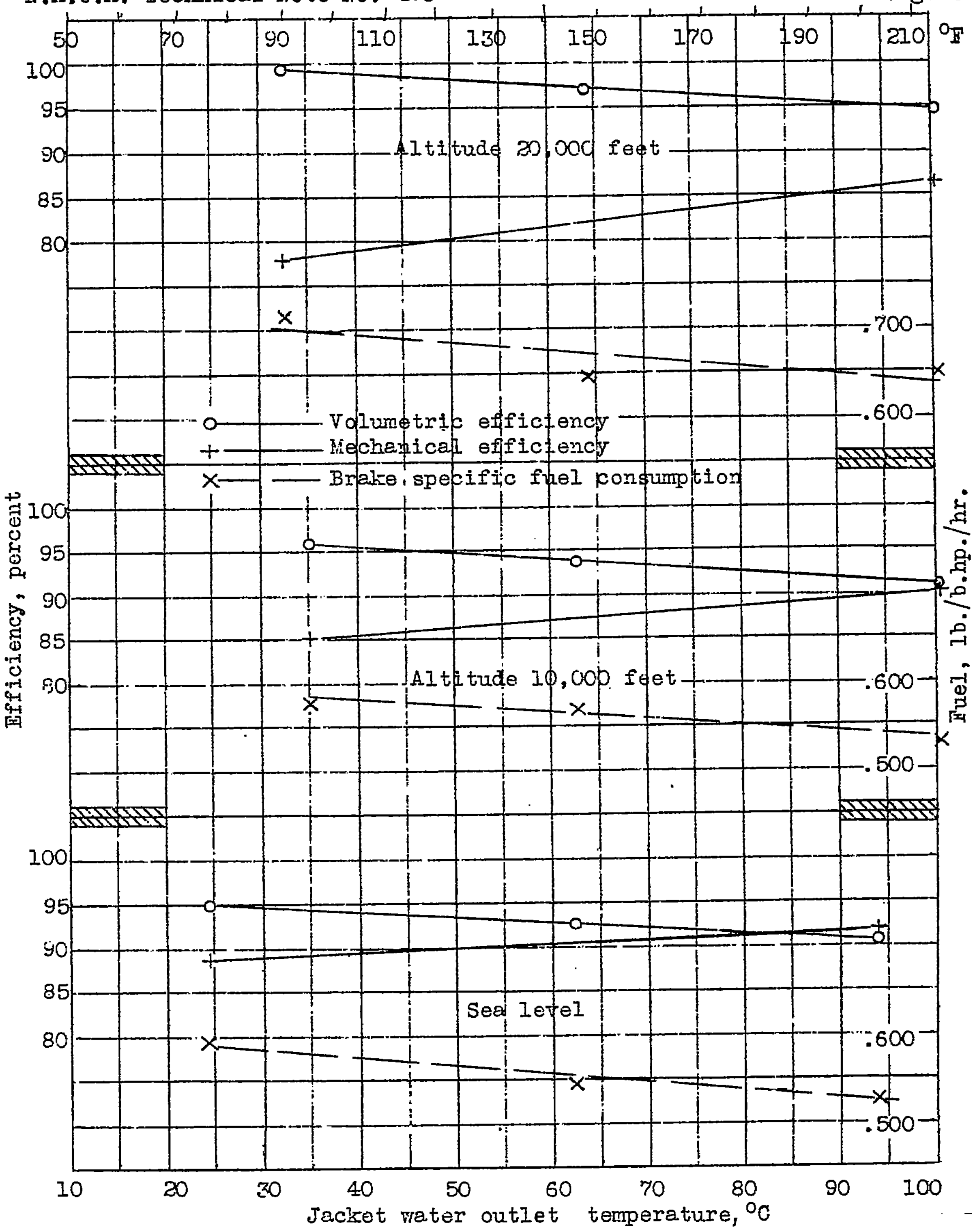
50
70
90
110
130
150
170
190
210
°F
100
95
90
85
80
Altitude 20,000 feet
.700
.600
Volumetric efficiency
Mechanical efficiency
Brake specific fuel consumption
100
95
90
85
80
Altitude 10,000 feet
.600
.500
100
95
90
85
80
Sea level
.600
.500
Efficiency, percent
Fuel, lb./b.hp./hr.
10
20
30
40
50
60
70
80
90
100
Jacket water outlet temperature, °C

Figure 3.

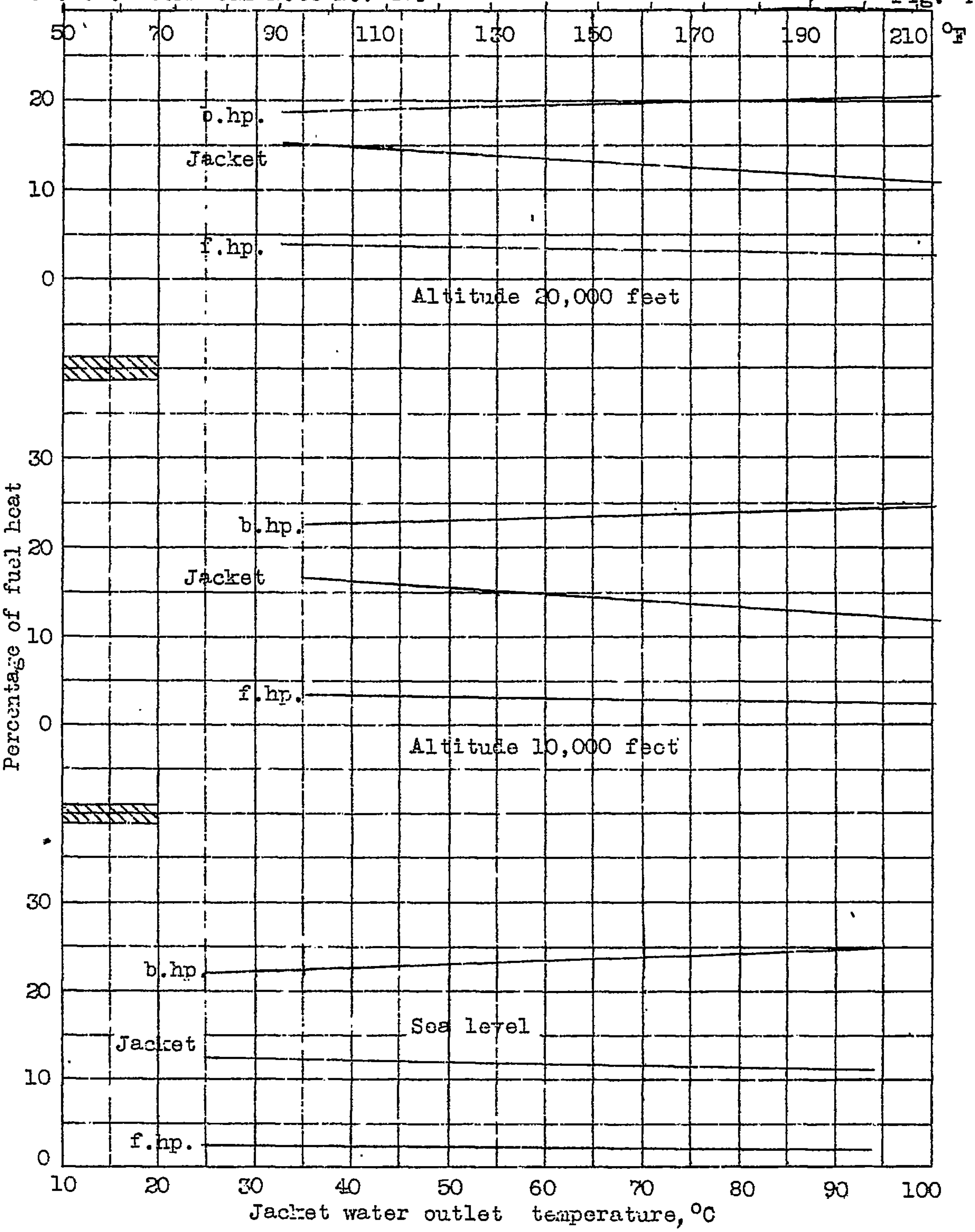
50
70
90
110
130
150
170
190
210
°F
20
b.hp.
Jacket
10
f.hp.
0
Altitude 20,000 feet
30
b.hp.
20
Jacket
10
f.hp.
0
Altitude 10,000 feet
30
b.hp.
20
Sea level
Jacket
10
f.hp.
0
Percentage of fuel heat
10
20
30
40
50
60
70
80
90
100
Jacket water outlet temperature, °C

Figure 4.