NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 698

PISTON TEMPERATURES IN AN AIR-COOLED ENGINE FOR VARIOUS OPERATING CONDITIONS

By EUGENE J. MANGANIELLO



1940

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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb.
Power	P	horsepower (metric)		horsepower	hp.
Speed	V	kilometers per hour	k.p.h.	miles per hour	m.p.h.
		meters per second	m.p.s.	feet per second	f.p.s.

2. GENERAL SYMBOLS

W, Weight$=mg$

g, Standard acceleration of gravity$=9.80665$ m/s^2 or 32.1740 ft./sec.^{2}

m, Mass$=\frac{W}{g}$

I, Moment of inertia$=mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C. and 760 mm; or 0.002378 lb.-ft.$^{-4}$ sec.^{2}

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb./cu. ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

$\frac{b^2}{S}$, Aspect ratio

V, True air speed

q, Dynamic pressure$=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

D_0, Profile drag, absolute coefficient $C_{D_0}=\frac{D_0}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i}=\frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p}=\frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force

i_w, Angle of setting of wings (relative to thrust line)

i_t, Angle of stabilizer setting (relative to thrust line)

Q, Resultant moment

Ω, Resultant angular velocity

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s., the corresponding number is 274,000)

C_p, Center-of-pressure coefficient (ratio of distance of c.p. from leading edge to chord length)

α, Angle of attack

ϵ, Angle of downwash

α_0, Angle of attack, infinite aspect ratio

α_i, Angle of attack, induced

α_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle

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By EUGENE J. MANGANIELLO

Langley Memorial Aeronautical Laboratory

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PISTON TEMPERATURES IN AN AIR-COOLED ENGINE FOR VARIOUS OPERATING CONDITIONS

By Eugene J. Manganiello

SUMMARY

As part of a program for the study of piston cooling, tests were conducted on a single-cylinder, air-cooled, carburetor engine to determine the effect of engine operating conditions on the temperature at five locations on the piston.

Indicated mean effective pressure, engine speed, fuel-air ratio, spark timing, cylinder temperature, oil temperature, and oil viscosity were each separately varied, the other conditions being held constant. The tests showed that the piston temperatures increased with indicated horsepower, the variation being slightly greater for a change in indicated horsepower obtained by varying the indicated mean effective pressure than for that obtained by increasing the speed. The piston temperatures varied linearly with cylinder temperature, increasing about 0.66° F per degree Fahrenheit rise in wall temperature; increased rapidly with increased spark advance; and increased as the mixture was enriched to a fuel-air ratio of about 0.077, decreasing with further enriching. Decreased oil viscosity resulted in a slight decrease of piston temperatures. Piston temperatures slightly decreased with an initial increase in oil (out) temperature and started increasing with a continued rise in oil temperature. A rough test indicated that the crankcase air and the oil thrown off from the bearings provide a small amount of piston cooling.

INTRODUCTION

The specific output of an aircraft engine is generally limited by the amount of cooling provided, insufficient cooling resulting in knock, ring failure, and piston failure. The heat-transfer processes in connection with cylinder temperatures in air-cooled engines have been successfully investigated by the N. A. C. A. and the design of finning for optimum cylinder cooling has been determined.

The problem of piston cooling, however, has not yet been satisfactorily analyzed because of insufficient piston-temperature data. This deficiency results from the lack, until recently, of a practicable method of measuring piston temperatures at the engine speeds in use at present. Several investigators (references 1 to 7) have reported the results of piston-temperature determinations made on compression-ignition and spark-ignition engines. The effects of the different engine operating conditions, however, were not isolated and the systems used for obtaining piston temperatures appeared to be limited to low engine speeds.

As part of a program for the study of piston cooling, the N. A. C. A. developed a satisfactory method of measuring piston temperature at high engine speeds. This report presents piston-temperature data obtained by this method at the Langley Memorial Aeronautical Laboratory between February and July 1939. The variation of piston temperatures with indicated mean effective pressure, engine speed, fuel-air ratio, spark timing, cylinder temperature, oil temperature, and oil viscosity was investigated on a single-cylinder, air-cooled, carburetor engine. A rough check of the piston cooling effected by the crankcase air and oil was also made.

APPARATUS AND METHODS

The engine used in the tests was an air-cooled, single-cylinder, carburetor test engine of 5¾-inch bore, 6-inch stroke, and a compression ratio of 5.72. The cylinder was mounted on an N. A. C. A. universal test-engine crankcase and was enclosed in a jacket through which cooling air was forced by a centrifugal blower (fig. 1). Beginning at the center line of the cylinder, a partition was provided in the jacket exit duct for separating the air that flowed over the barrel from the air that flowed over the head. (See fig. 1 of reference 8.) The temperatures of the cylinder were measured by 21 thermocouples on the head, 11 on the barrel, and 2 on the flange. The location of these thermocouples was the same as that of reference 9. The standard test-engine equipment was used for measuring brake mean effective pressure, engine speed, and fuel consumption. The mixture strength was determined in most of the tests from gasometer measurements of the air quantity supplied to the engine and from the fuel-consumption measurements. In the tests with boost pressure, the mixture strength was determined by means of a calibrated Cambridge fuel-air-ratio meter.

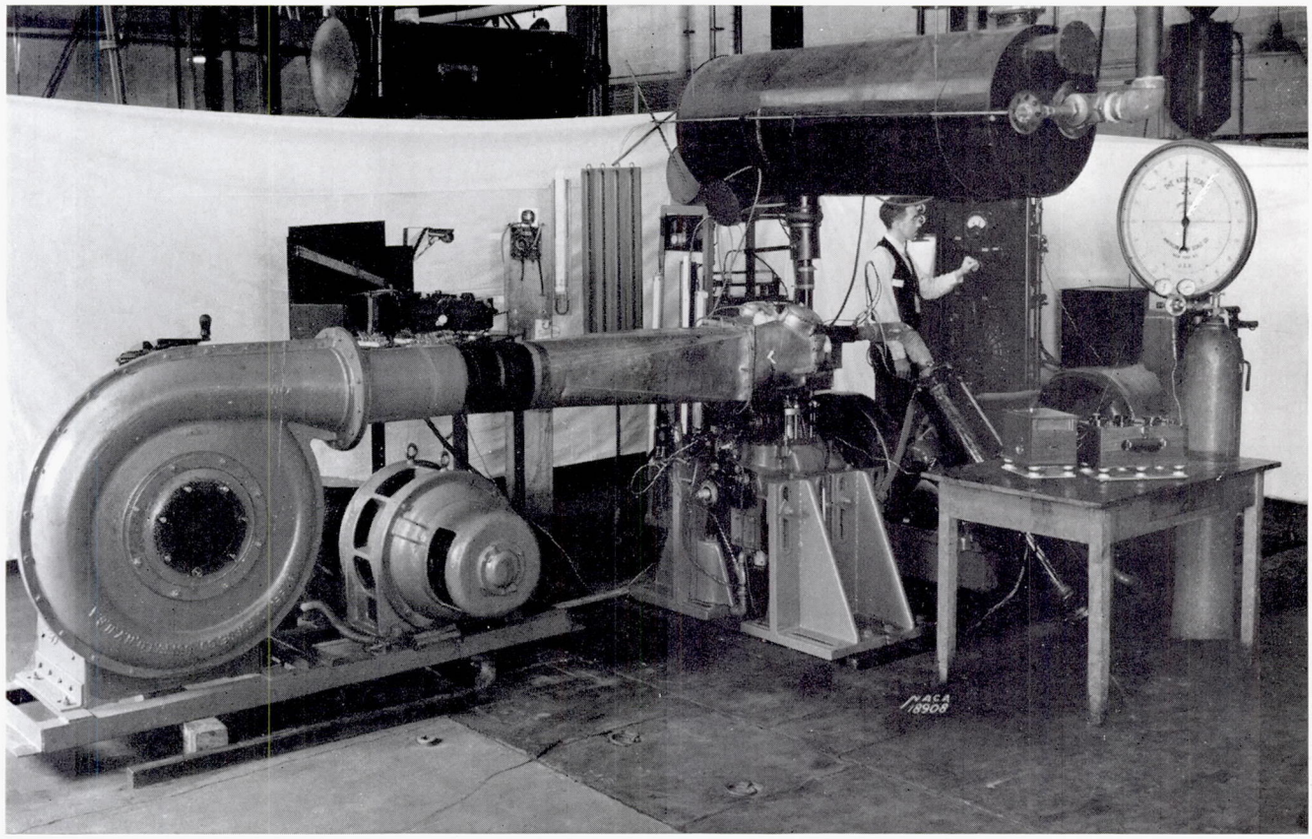
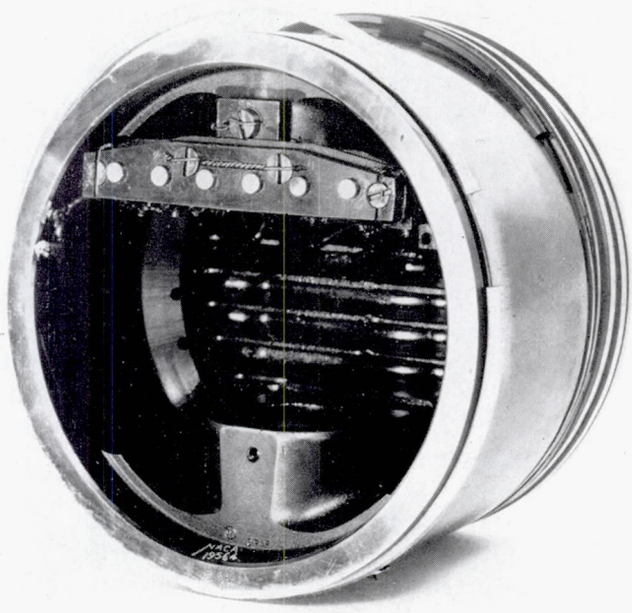
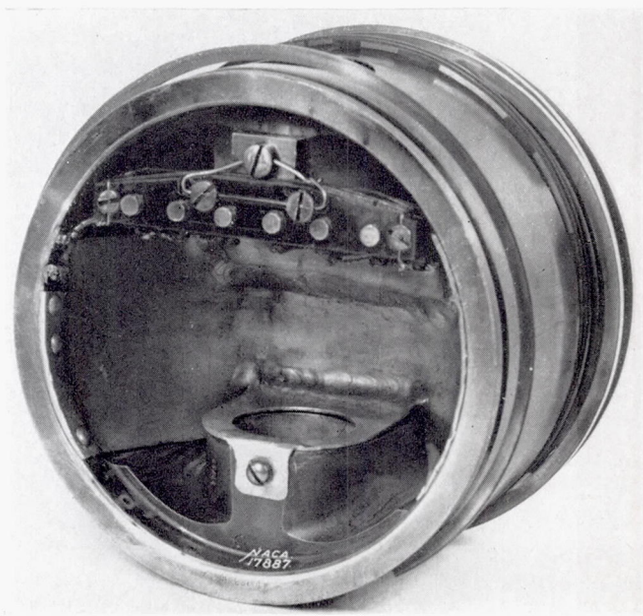


FIGURE 1.—The single-cylinder test engine with auxiliary equipment



(a) Without baffle.



(b) With baffle.

FIGURE 2.—The air-cooled engine piston (showing contacts).

The piston on which the tests were made (fig. 2(a)) was a standard engine aluminum-alloy piston with three compression rings, an oil-control ring, and an oil-scraper ring. The piston clearance was 0.025 inch at the skirt, 0.032 inch at the ring belt, and 0.038 at the top land.

Piston temperatures were obtained by a method employing thermocouples, the circuits of which were closed

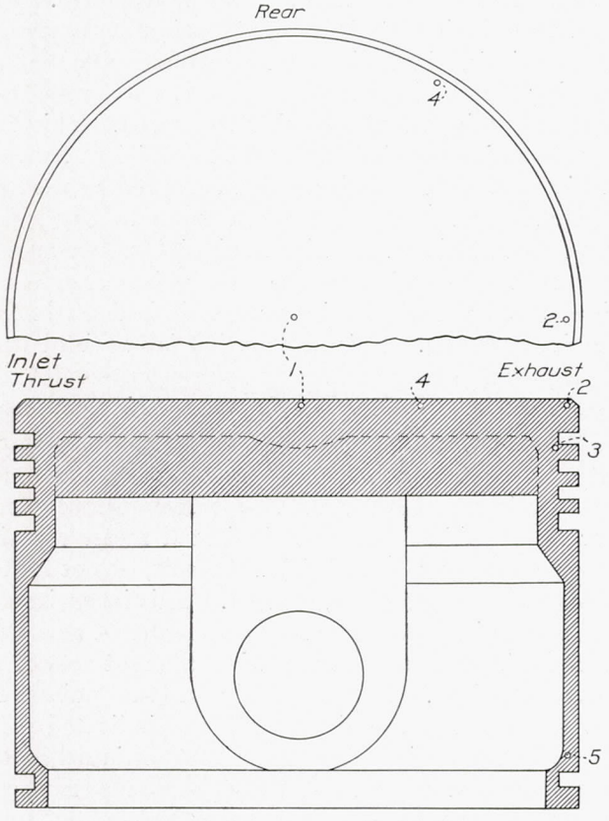


FIGURE 3.—Location of piston thermocouples.

by contacts for a few crank-angle degrees at bottom center. (See reference 10.) The thermal electromotive forces were measured with a potentiometer.

Five thermocouples were installed in the piston at the following locations (fig. 3): 1, center of the crown; 2, exhaust-side edge of the crown; 3, behind the lower edge of the top-ring groove on the exhaust side of the piston; 4, rear edge of the crown; and 5, above the scraper-ring groove on the exhaust side of the piston.

Thermocouples 1, 2, 3, and 4 were insulated from the piston metal to within 1/16 inch of the outside surface of the piston so that the temperatures measured were practically surface temperatures. Thermocouple 5 was attached to the inside surface of the skirt but, as the temperature gradient through the 3/64-inch thickness of aluminum alloy at that location is small, the measurements obtained for location 5 may also be considered surface temperatures.

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Piston temperatures were obtained over the following range of engine conditions:

Indicated mean effective pressure, pounds per square inch	95–258
Engine speed, rpm	1,200–2,100
Fuel-air ratio	0.06–0.09
Spark advance, degrees B. T. C	8–46
Barrel temperature (average), °F	175–260
Head temperature (average), °F	200–300
Oil (out) temperature, °F	130–195

Each of these factors was separately varied, the others being held constant. The cylinder temperatures were controlled by varying the pressure drop of the cooling air. Tests with variable indicated mean effective pressure were also made with constant cooling-air pressure drop.

In the variable spark-advance tests the weight of charge, rather than the indicated mean effective pressure, was held constant. Two tests with variable fuel-air ratio were made, one with constant weight of charge and constant spark and the other with constant indicated mean effective pressure and optimum spark.

The relative effect of head and barrel temperatures on piston temperatures was determined by blocking, in turn, the jacket exits for the head and the barrel cooling air.

In one series of tests, a metal baffle was fastened to the underside of the piston crown (fig. 2 (b)) and the cylinder temperatures were varied, the other engine conditions being held constant, to determine the effect of crankcase oil and air on piston cooling.

The oil (out) temperature was held at 145° F (±10° F) in all of the tests except those of variable oil temperature. The tests were made with an S. A. E. 60 lubricating oil. An additional test was made with S. A. E. 30 oil, in which the cylinder temperatures were varied and the other engine conditions were held constant. The specific gravity and the viscosity of the oils used are listed in the following table.

Oil	Specific gravity	Absolute viscosity (lb/ft sec)		
		200° F	350° F	400° F
S. A. E. 60	0.886	0.01600	0.00280	0.00196
S. A. E. 30	.925	.00623	.00130	.00094

Engine-friction measurements were repeated at intervals during the period of time spent on the tests for a range of speeds and manifold pressures.

The piston rings were replaced before the completion of the tests.

Sufficient time was allowed after a change in engine test conditions to insure equilibrium before readings were recorded.

RESULTS AND DISCUSSION

REPRODUCIBILITY AND ACCURACY

The piston temperatures herein presented were generally reproducible within a range of 15° F for the same conditions. Occasionally, however, greater dispersion occurred, particularly in the case of the ring-groove temperature. This scatter is considered to be due to the changing condition of the piston rings with engine running time and operation. Changes in the seating of the rings result in varying amounts of blowby, which influences the piston temperatures. This difference in piston temperatures for the same engine conditions was particularly noticeable between results obtained before and after ring replacement.

In addition to dependence upon ring condition, the piston temperatures were found to be sensitive to slight variations in engine operation. These variations were generally not indicated by changes in other engine variables and may have been due to differences in ignition, combustion, and lubrication.

The results are considered to be representative of normal operation of the engine used in the tests for the specified conditions and with good ring-seating conditions.

The variation of the piston temperatures with the different engine conditions is shown in figures 4 to 12. The temperatures of the piston at the various thermocouple locations are plotted as separate curves, the numbers of which correspond to the numbers of the locations shown in figure 3. The temperature T_b, the average of the readings of the 11 barrel thermocouples, and the temperature T_h, the average of the readings of the 21 head thermocouples, are also plotted for reference.

PISTON-TEMPERATURE DISTRIBUTION

The center of the piston, represented by curve 1 (figs. 4 to 12), attained a higher temperature than any of the other locations measured. The edge of the crown, curves 2 and 4, ran between 5° and 35° F cooler; the ring groove, curve 3, between 30° and 70° F cooler; and the lower portion of the skirt, curve 5, between 110° and 160° F cooler. It is noted that location 2 usually was at a higher temperature but occasionally was at the same or a lower temperature than location 4. This variation appears to be haphazard and unrelated to the change in any of the engine conditions.

The variation in the difference between the temperature of the ring groove, curve 3, and the center of the crown, curve 1, is believed to be caused by change in the ring condition.

INDICATED HORSEPOWER

The effect of indicated mean effective pressure on the piston temperatures is shown in figures 4 and 5. The results plotted in figure 4 were obtained with part-throttle to full-throttle operation at 2,100 rpm and with the cylinder temperatures held constant. Figures 5 (a) and 5 (b) were obtained by boosting at 2,100 and 1,500 rpm, respectively, with the jacket pressure drop held constant. The variation of piston temperatures with engine speed is shown in figure 6. The effect of engine speed on piston temperatures can also be obtained from a comparison of figures 5 (a) and 5 (b).

These results show an increase in piston temperatures with an increase in indicated horsepower. The percentage rise in piston temperatures is slightly greater for a variation in indicated horsepower obtained by changing the indicated mean effective pressure than for that obtained by increasing the speed. This fact suggests an increase in heat-transfer coefficient between the piston and the cylinder walls with speed, as the heat transferred from the combustion gases to the piston may be assumed to vary with the indicated horsepower independently of whether the change in power is obtained through variation in speed or in indicated mean effective pressure. This assumption is obtained from analogy to the case of heat transfer from combustion gases to the head and the barrel, as treated in reference 8.

If the piston temperatures shown in figure 5 (a) are corrected to the cylinder temperatures shown in figure 4, fairly smooth curves of piston temperatures over the combined range of indicated mean effective pressure of figures 4 and 5 (a) will result, except for the ring-groove temperatures, curve 3. This inconsistency may be due in part to the fact that figures 4 and 5 (a) were obtained from tests run with different sets of replacement rings. The crossover of the points for curves 2 and 4 at the highest value of indicated mean effective pressure in figure 4 and the continued higher temperature of location 4 throughout the range of figure 5 are also noted.

FUEL-AIR RATIO

The variation of piston temperatures with fuel-air ratio is shown in figure 7. The results of figure 7 (a) were obtained at constant weight of charge and constant spark advance; whereas, those of figure 7 (b) were obtained at constant indicated mean effective pressure and optimum spark advance.

Of the two parts of figure 7, figure 7 (a) is to be preferred for illustrating the effect of fuel-air ratio on piston temperatures because all of the other engine variables that affect the heat-transfer processes in the engine were held constant. It is recalled that weight of charge, rather than indicated mean effective pressure, is the fundamental variable in the heat transfer from the combustion gases (reference 8).

The increase in piston temperatures with increase in mixture strength from the lean range to a fuel-air ratio of about 0.077 and the decrease in temperature with further enriching may be attributed to variation in the effective gas temperature with fuel-air ratio (reference 8).

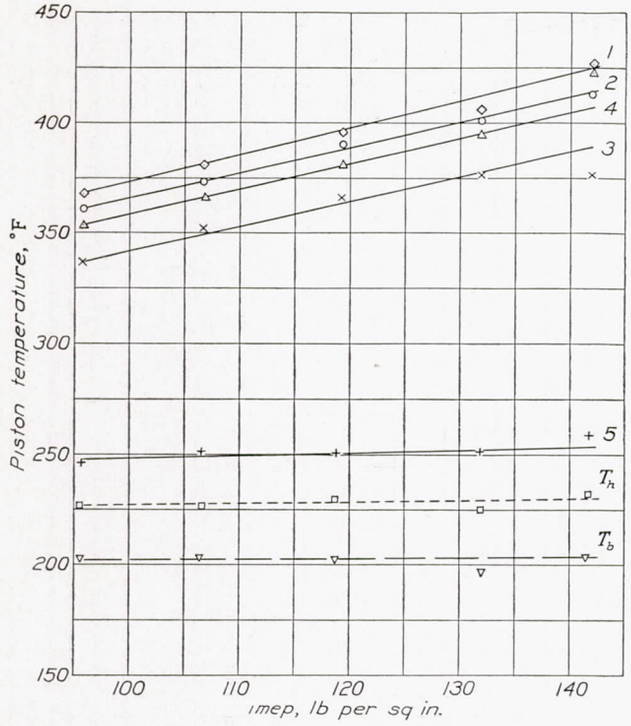


FIGURE 4.—Variation of piston temperatures with indicated mean effective pressure. Engine speed, 2,100 rpm; fuel-air ratio, 0.08; spark advance, 31° B. T. C.; constant head and barrel temperatures.

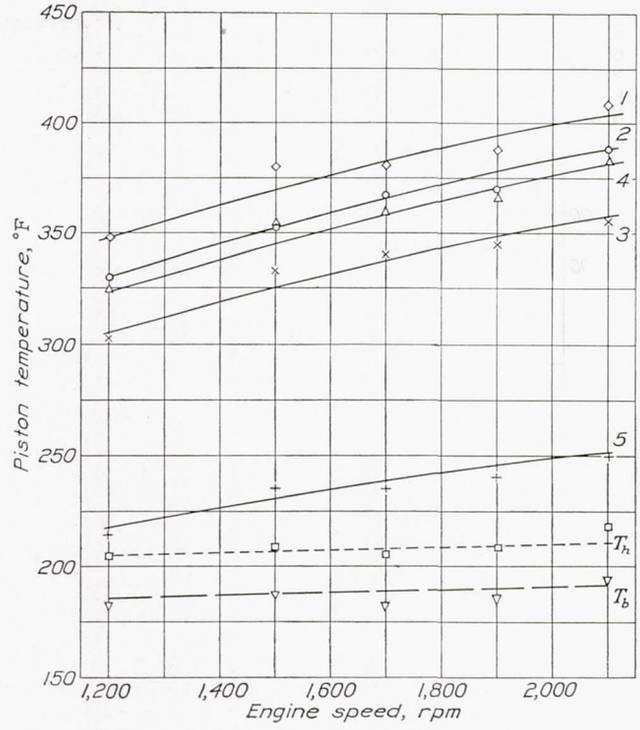
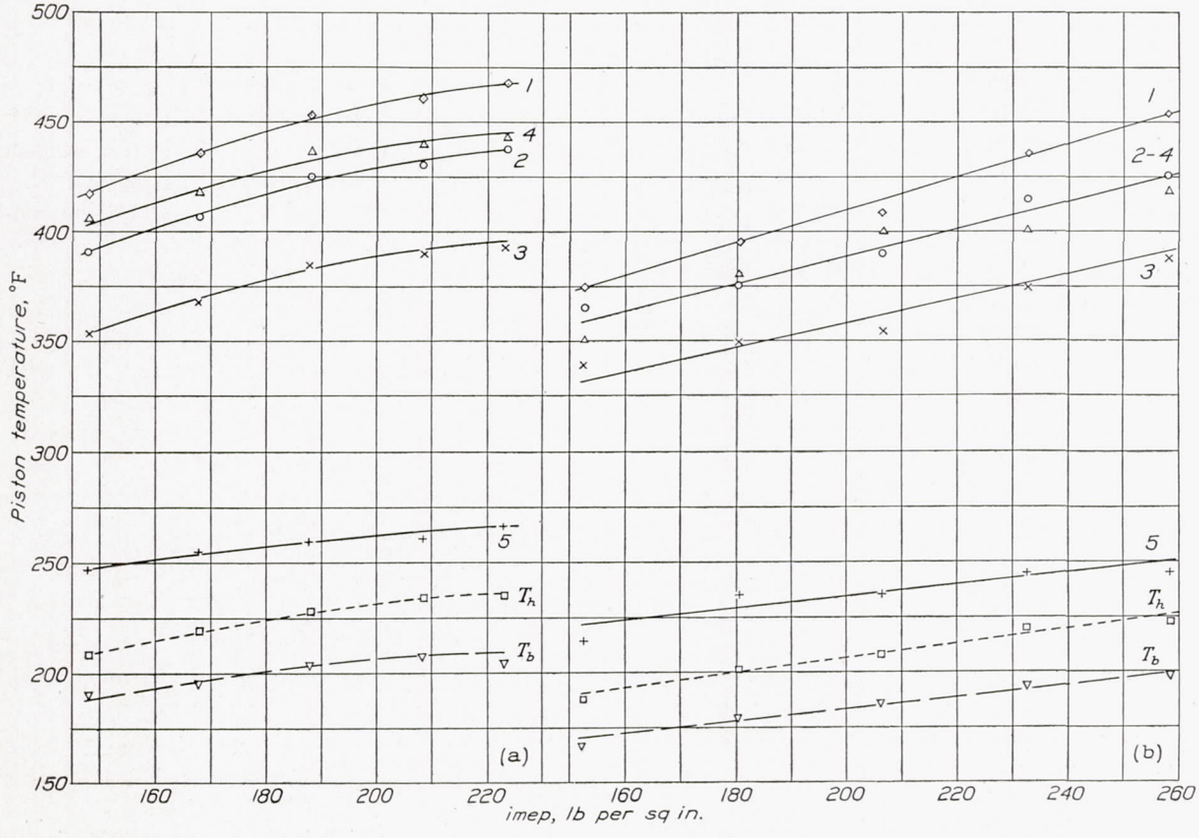


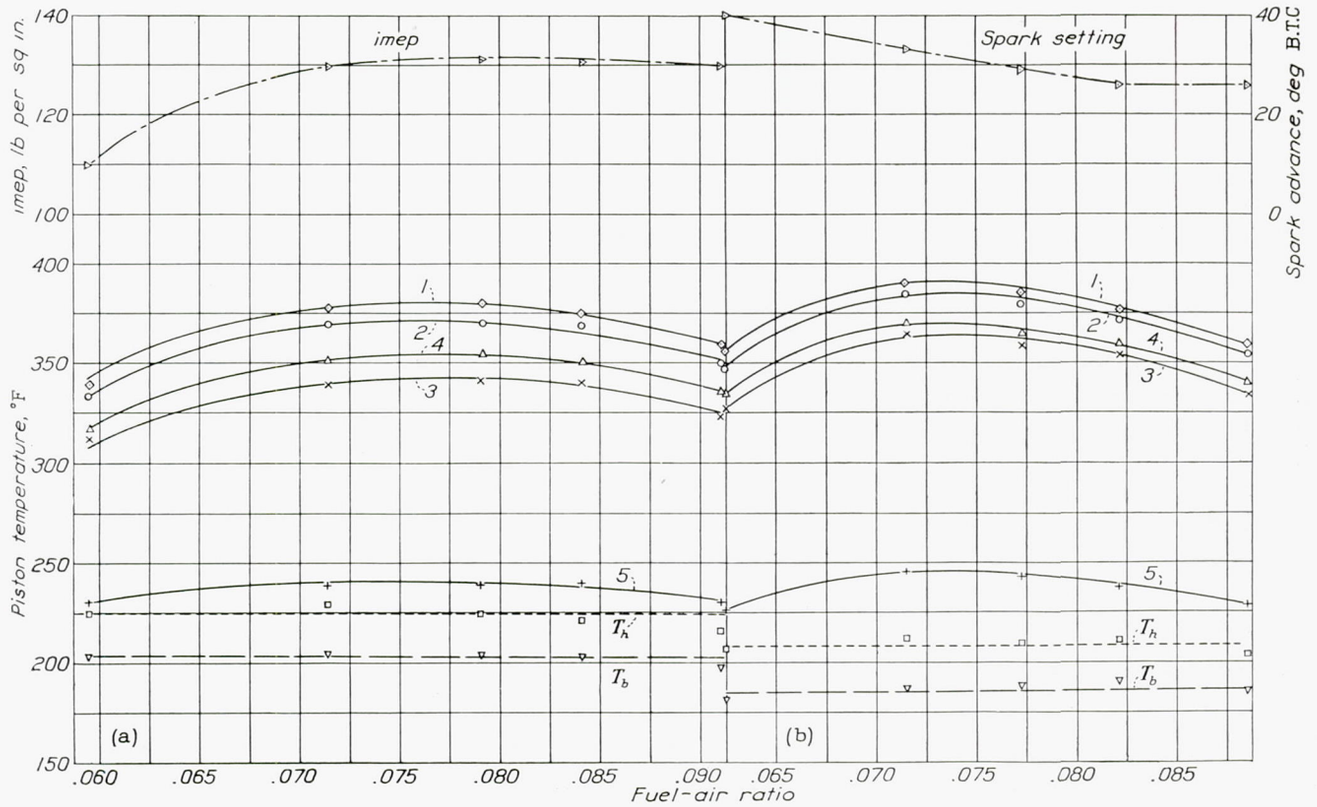
FIGURE 6.—Variation of piston temperatures with engine speed. Fuel-air ratio, 0.08; spark advance, 26° B. T. C.; indicated mean effective pressure, 137 pounds per square inch; constant head and barrel temperatures.



(a) Engine speed, 2,100 rpm; spark advance, 30° B. T. C.

(b) Engine speed, 1,500 rpm; spark advance, 28° B. T. C.

FIGURE 5.—Variation of piston temperatures with indicated mean effective pressure; boosted performance. Fuel-air ratio, 0.08; constant jacket pressure drop.



(a) Spark advance, 26° B. T. C.; constant weight of charge.

(b) Spark advance, optimum; indicated mean effective pressure, 133 pounds per square inch.

FIGURE 7.—Variation of piston temperatures with fuel-air ratio. Engine speed, 1,500 rpm; constant head and barrel temperatures.

SPARK ADVANCE

The effect of spark advance on piston temperatures is shown in figure 8. These results were obtained at 1,500 and 2,100 rpm for nonknocking operation, the weight of charge, the cylinder temperatures, and the other engine conditions being held constant.

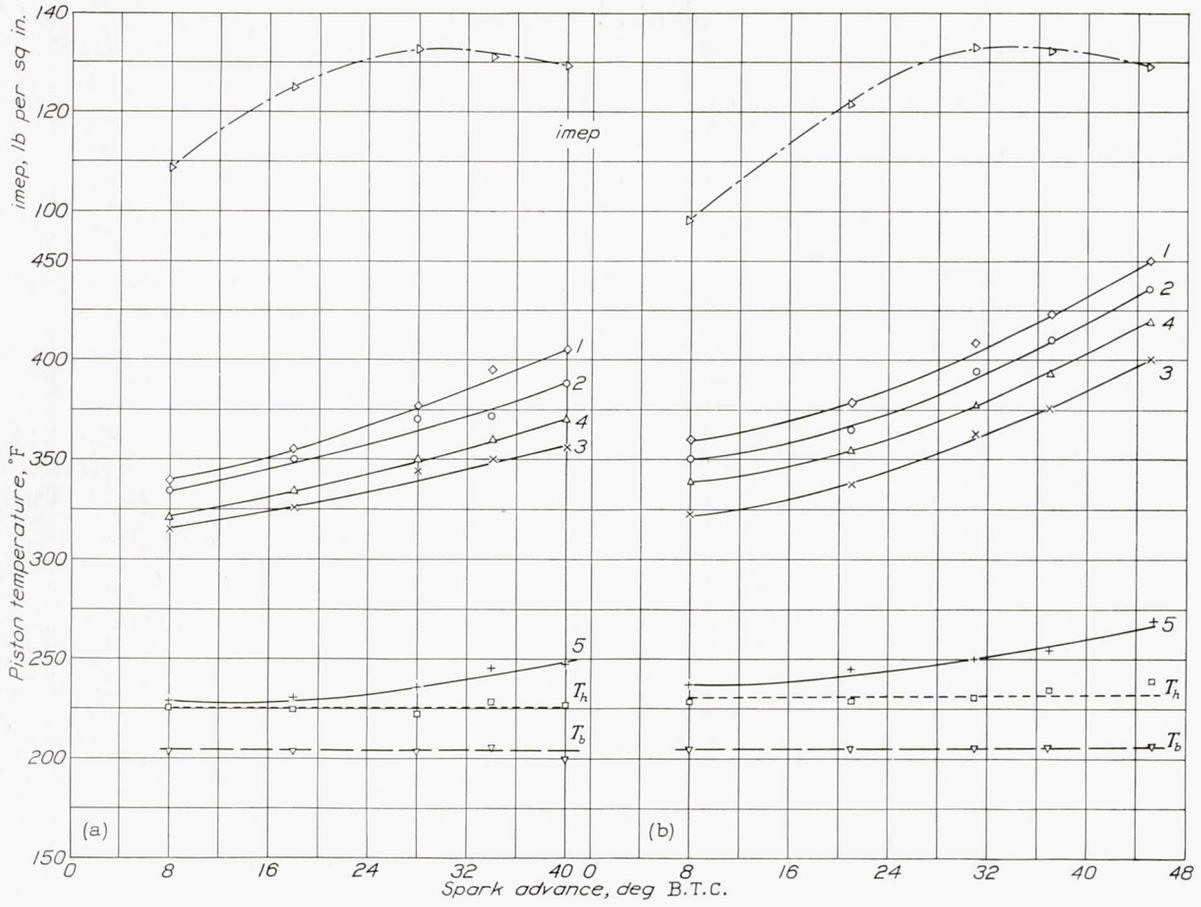
The increase of piston temperatures with increase in spark advance over the range tested is surprisingly large. Reference 8 indicates that the variation of cylinder-head and cylinder-barrel temperatures with spark advance is small, the cylinder temperatures remaining practically constant over a wide range of spark setting and increasing slightly for both greatly advanced and greatly retarded spark timings. This variation of cylinder temperature with spark setting was qualitatively checked in these tests in that small increases in cooling-air mass flow were required to maintain constant head and barrel temperatures at the extremes of the spark-setting range.

The variation of cylinder-wall temperature with spark timing is thus seen to be an unreliable index of the variation of piston temperature with regard to both magnitude and direction.

CYLINDER TEMPERATURE

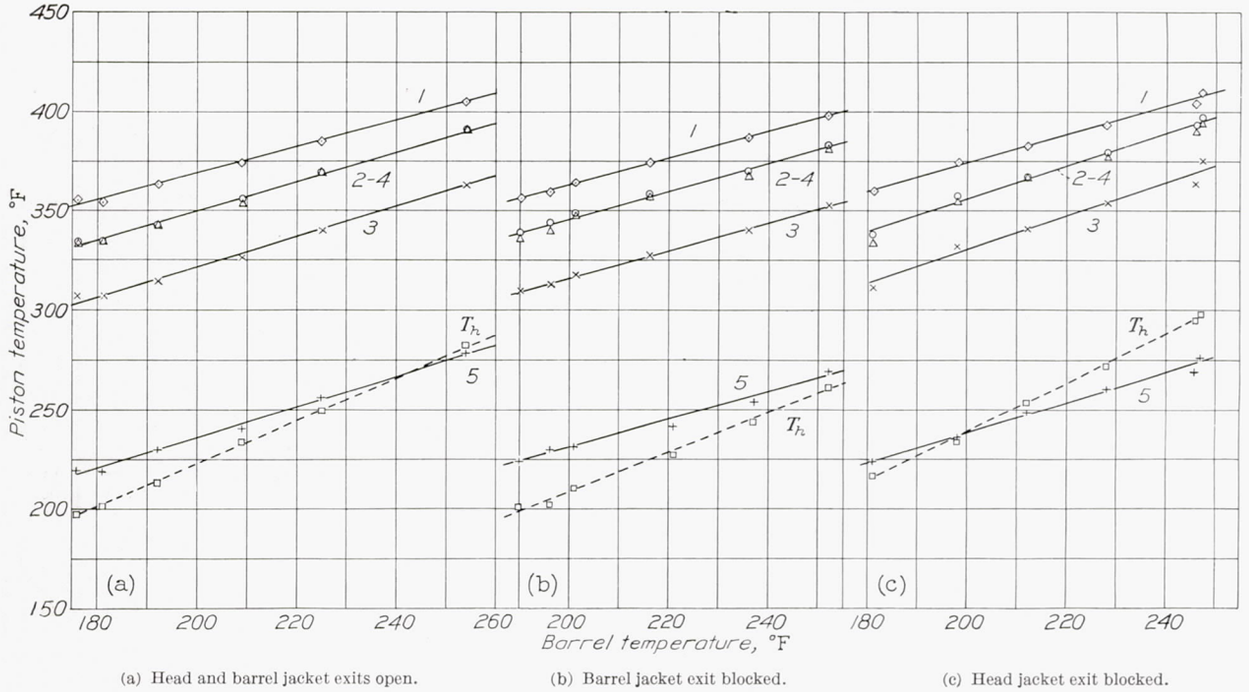
Figure 9 (a) shows the variation of piston and average head temperatures with barrel temperature, which was varied by varying the rate of cooling-air flow. The piston temperatures increased 0.66° F per degree Fahrenheit increase in barrel temperature, and the average head temperature increased 1.08° F. Additional tests were made with the same engine conditions but with the jacket exit for the barrel cooling air blocked in one case and with the jacket exit for the head cooling air blocked in the other case. The results of these tests are shown in figures 9 (b) and 9 (c), respectively. A comparison of figure 9 (b) with 9 (a) shows that blocking the barrel resulted in average head temperatures about 15° F lower than normal for a given barrel temperature, which lowered the piston temperature about 5° F with no appreciable change in slope. A comparison of figure 9 (c) with 9 (a) shows that blocking the head increased the average head temperatures about 18° F for a given barrel temperature, resulting in a piston-temperature rise of about 6° F, again with no change in slope. From this comparison of figures 9 (a), 9 (b), and 9 (c), it appears that, of the total effect of cylinder temperature on piston temperature, 50 percent is due to change in barrel temperature and 50 percent is due to change in head temperature.

These values, which indicate the relative importance of head and barrel temperature in controlling piston temperature, were determined for small differences in



(a) Engine speed, 1,500 rpm. (b) Engine speed, 2,100 rpm.

FIGURE 8.—Variation of piston temperatures with spark advance. Fuel-air ratio, 0.08; constant weight of charge; constant head and barrel temperatures.



(a) Head and barrel jacket exits open. (b) Barrel jacket exit blocked. (c) Head jacket exit blocked.

FIGURE 9.—Variation of piston temperatures with barrel temperature. Engine speed, 1,500 rpm; fuel-air ratio, 0.08; spark advance, 26° B. T. C.; indicated mean effective pressure, 133 pounds per square inch.

piston temperature and are therefore rather unreliable. Two similar sets of tests, for instance, indicated that the variation of barrel temperature is responsible for 75 percent of the change in piston temperature in one case and for 33 percent in the other, as contrasted with the 50-percent change obtained from figures 9 (a), 9 (b), and 9 (c). All these tests, however, gave the same value for the over-all effect, that is, 0.66° F rise in piston temperature per degree Fahrenheit rise in barrel temperature when the head temperature was allowed to vary with the barrel temperature in the normal manner. This value probably depends slightly on the engine operating conditions.

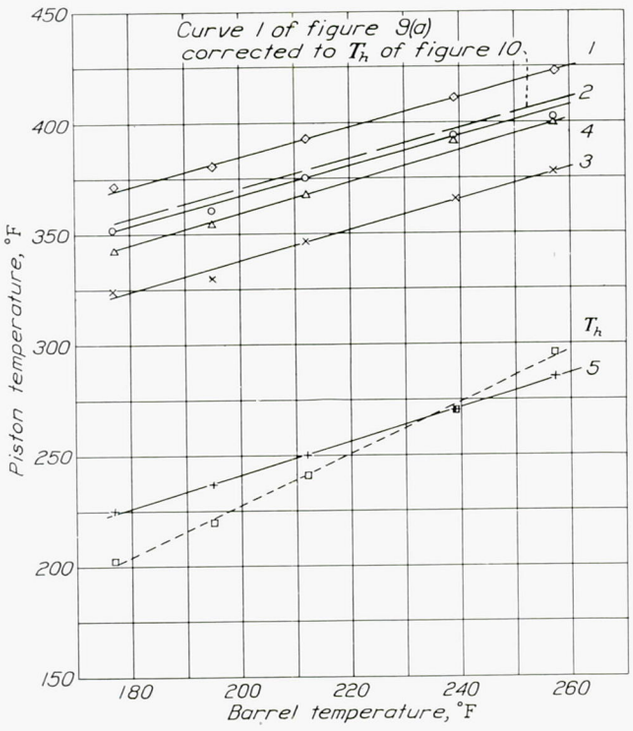


FIGURE 10.—Variation of piston temperatures with barrel temperature; piston baffled. Engine speed, 1,500 rpm; fuel-air ratio, 0.08; spark advance, 26° B. T. C.; indicated mean effective pressure, 133 pounds per square inch.

It is hoped that future tests providing, among other things, for greater change in relative head and barrel temperatures will permit isolating the effects of head and barrel temperatures on piston temperature.

PISTON COOLING BY CRANKCASE AIR AND OIL

The variation of piston temperatures with barrel temperature for the baffled-piston condition is shown in figure 10. In these tests, a metal plate was fastened to the piston (fig. 2 (b)) in order to prevent the crankcase oil and air from making active contact with the underside of the crown. The engine conditions were the same as those of figure 9 (a), curve 1 of which is included in figure 10 for convenience. Comparison of figure 10 with 9 (a) shows piston temperatures to be about 15° F higher for the baffled-piston condition than for the normal condition, indicating that a small amount of piston cooling is effected by crankcase air and the oil thrown from the bearings. The magnitude of this effect may be expected to vary with different types of engine because of differences in crankcase design. Supplementary oil supply to the piston by means of directed jets will have an appreciable cooling effect.

OIL VISCOSITY AND TEMPERATURE

The effect of oil viscosity on piston temperatures is obtained from a comparison of figures 11 and 9 (a). Curve 1 of figure 9 (a), corrected to the cylinder-head temperatures of figure 11, is included in figure 11 for convenience. The results shown in figure 11 were obtained under the same test conditions as those of figure 9 (a) except that a lighter lubricating oil was used. The change from S. A. E. 60 oil, which was used for all of the other tests, to S. A. E. 30 oil (fig. 11) resulted in a decrease in piston temperature of about 20° F, correction being made for the higher average cylinder-head temperature of figure 11. This decrease in piston temperatures with decreased oil viscosity may be due to one or more of the following factors: (1) Improvement in the heat transfer between the piston and the cylinder walls; (2) decrease in friction heating; (3) increased oil flow and consequently greater oil cooling of the piston; and (4) unobserved changes in engine conditions.

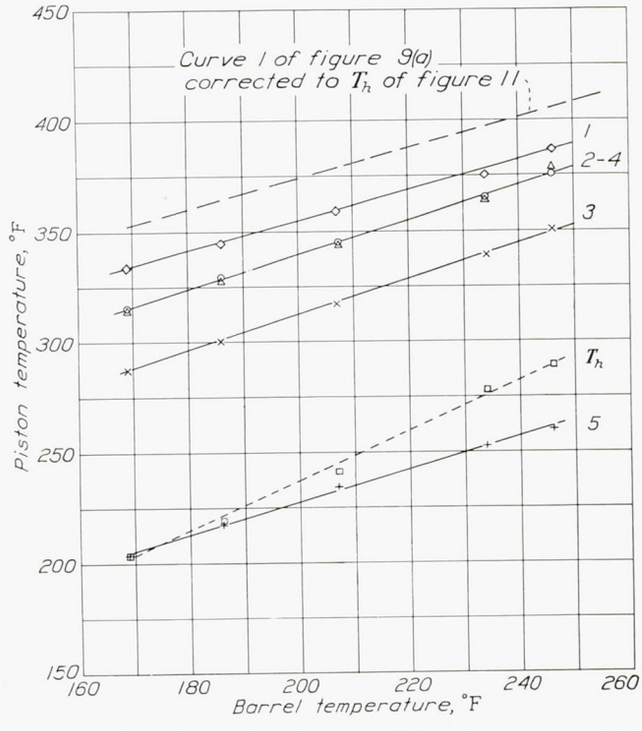


FIGURE 11.—Variation of piston temperatures with barrel temperature; light oil. Engine speed, 1,500 rpm; fuel-air ratio, 0.08; spark advance, 26° B. T. C.; indicated mean effective pressure, 133 pounds per square inch.

The variation of piston temperatures with oil (out) temperature for constant engine conditions and cylinder temperatures is shown in figure 12. The decrease

in piston temperatures with initial increase in oil temperature is probably due to the viscosity effects previously indicated. The leveling off and the subsequent increase of piston temperatures with further increase in oil temperature may be the result of the counteraction

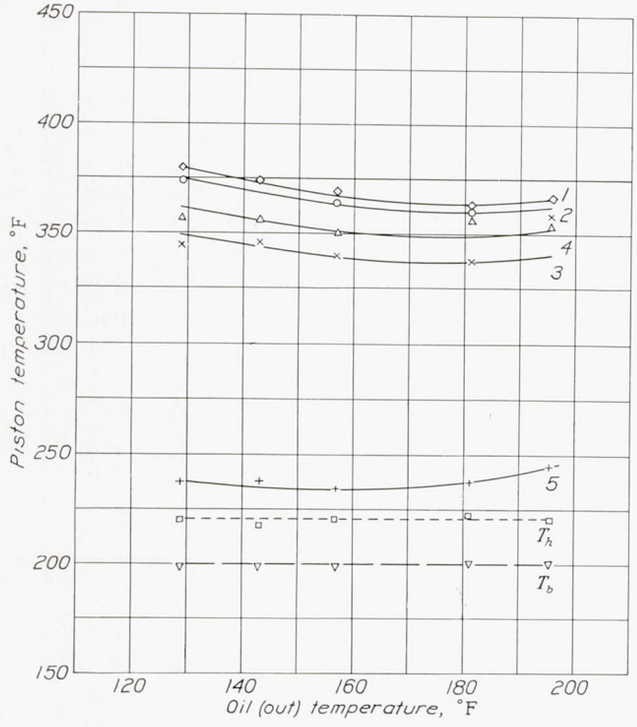


FIGURE 12.—Variation of piston temperatures with oil (out) temperature. Engine speed, 1,500 rpm; fuel-air ratio, 0.08; spark advance, 28° B. T. C.; indicated mean effective pressure, 133 pounds per square inch; constant head and barrel temperatures.

of decreased oil cooling of the piston with increased oil temperature.

CONCLUSIONS

The results of the present investigation showed that piston temperatures:

1. Rose with increase of indicated horsepower, the variation being slightly greater for change in indicated horsepower obtained by varying the indicated mean effective pressure than for that obtained by increasing the engine speed.

2. Increased as the mixture was enriched to a fuel-air ratio of about 0.077 and decreased with further enriching.

3. Increased rapidly with increase of spark advance for constant cylinder temperature.

4. Varied linearly with cylinder temperature, increasing about 0.66° F per degree Fahrenheit rise in barrel temperature.

5. Were slightly affected by oil viscosity, a change from S. A. E. 60 oil to S. A. E. 30 oil resulting in about a 20° F decrease in piston temperatures.

6. Decreased slightly with increase in oil (out) temperature within normal operating limits but increased with further rise in oil temperature.

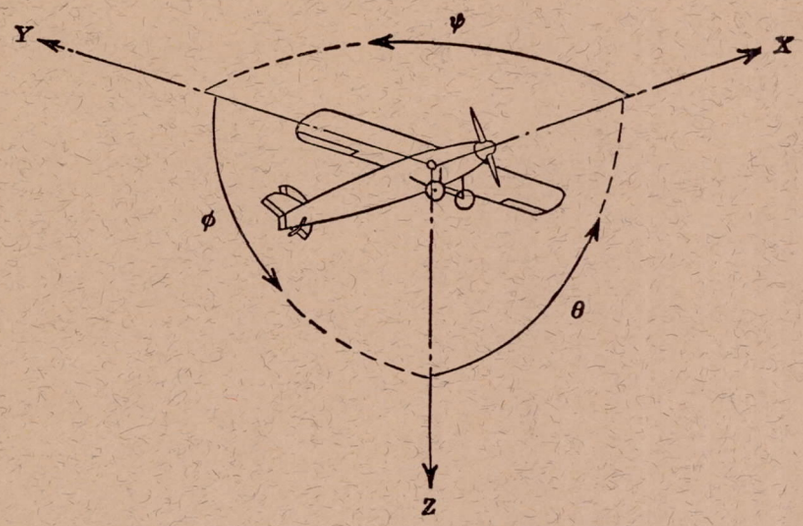
7. Increased slightly when the piston crown was shielded from the crankcase air and oil.

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Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	Rolling	L	$Y \longrightarrow Z$	Roll	ϕ	u	p
Lateral	Y	Y	Pitching	M	$Z \longrightarrow X$	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	$X \longrightarrow Y$	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l = \frac{L}{qbS}$ (rolling) $\quad C_m = \frac{M}{qcS}$ (pitching) $\quad C_n = \frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter

p, Geometric pitch

p/D, Pitch ratio

V', Inflow velocity

V_s, Slipstream velocity

T, Thrust, absolute coefficient $C_T = \frac{T}{\rho n^2 D^4}$

Q, Torque, absolute coefficient $C_Q = \frac{Q}{\rho n^2 D^5}$

P, Power, absolute coefficient $C_P = \frac{P}{\rho n^3 D^5}$

C_s, Speed-power coefficient $= \sqrt[5]{\frac{\rho V^5}{P n^2}}$

η, Efficiency

n, Revolutions per second, r.p.s.

Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp.=76.04 kg-m/s=550 ft-lb./sec.

1 metric horsepower=1.0132 hp.

1 m.p.h.=0.4470 m.p.s.

1 m.p.s.=2.2369 m.p.h.

1 lb.=0.4536 kg.

1 kg=2.2046 lb.

1 mi.=1,609.35 m=5,280 ft.

1 m=3.2808 ft.