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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 550

COOLING CHARACTERISTICS OF A 2-ROW RADIAL ENGINE

By OSCAR W. SCHEY and VERN G. ROLLIN

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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 meters per second	k.p.h. m.p.s.	miles per hour feet per second	m.p.h. 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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Langley Memorial Aeronautical Laboratory

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miles per hour was [illegible] cooling of this engine, as installed in a Vought XO4U-2 airplane with air of standard sea-level density when operating at full throttle at an engine speed of 2,500 r. p. m. Increasing the brake horsepower 50 percent resulted in an increase of 13 to 20 percent in the temperature difference between the air and the cooling surface. When the air speed was increased from 60 to 120 miles per hour, there was a decrease in the temperature difference between the cooling air and the cooling surface of only 17 percent. The same percentage change in temperature difference between the cooling air and the cooling surface was obtained for a given change in power when the manifold pressure was varied as when the engine speed was varied. The effect of the attitude of the airplane on the cylinder temperatures was small; the temperatures increased or decreased slightly, depending on the location of the cylinder. The difference in cylinder temperatures obtained with 3-blade and 2-blade propellers was negligible. The heat loss through the oil radiator was equal to from 3 to 6 percent of the heat going into indicated power, depending on engine speed and mixture strength.

INTRODUCTION

Many investigations have been conducted on air-cooled engines, particularly engines of the single-row radial type, for the purpose of studying the cooling obtained with different types of cowlings. Although most of these investigations have yielded a large amount of valuable information, there still remain important factors to be investigated.

Remarkable progress has been made in the cooling of air-cooled engines but cooling difficulties frequently occur because aircraft engines are required to operate, at least part of the time, under very severe conditions. Furthermore, reduction gears, controllable propellers, increased specific outputs, superchargers, and, in some , low-drag cowlings have all intensified cooling lties.

present investigation was undertaken at the st of the Bureau of Aeronautics, Navy Department, to determine the cooling of a 2-row radial e under conditions closely simulating those in especially those of the full-throttle climb. In tests the many factors influencing the cooling aried over a range sufficiently large that their could be established. In general, the cylinder eratures were measured at various engine speeds, manifold pressures, speeds of cooling air, and fuel consumptions. Tests were also made with a 2-blade and 3-blade propeller and with the airplane at different angles of attack.

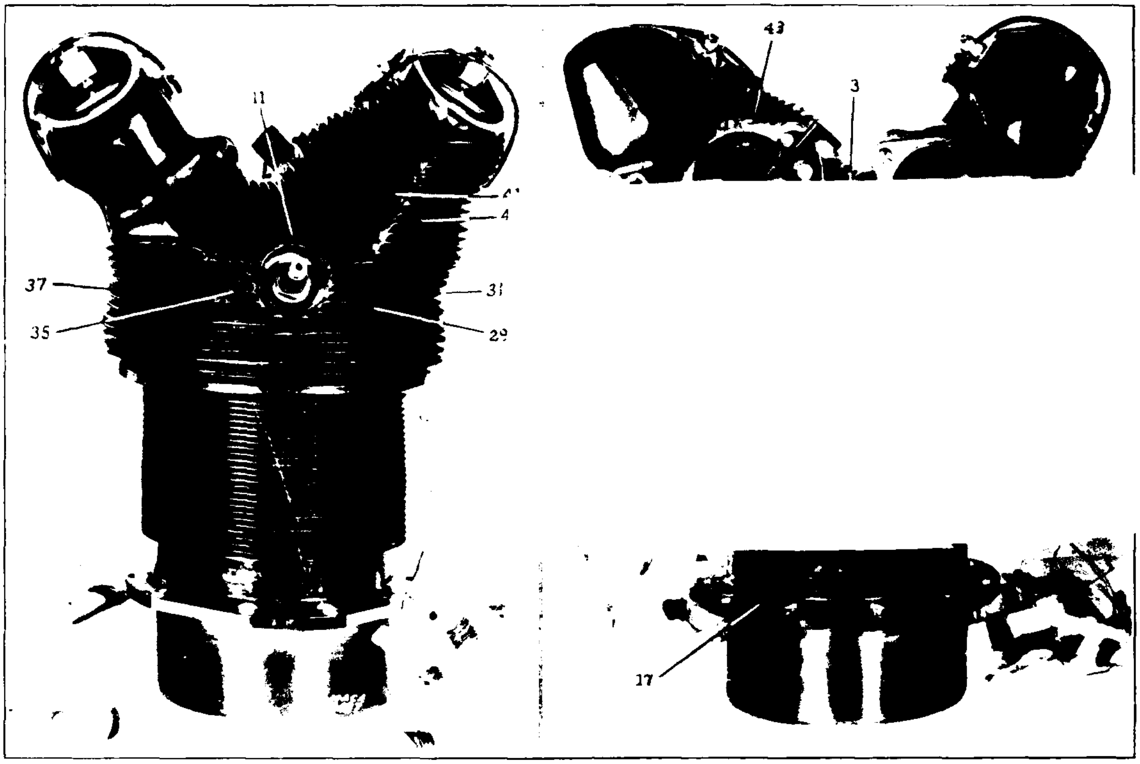
The tests were conducted by the National Advisory Committee for Aeronautics during April and May 1933.

DESCRIPTION OF EQUIPMENT

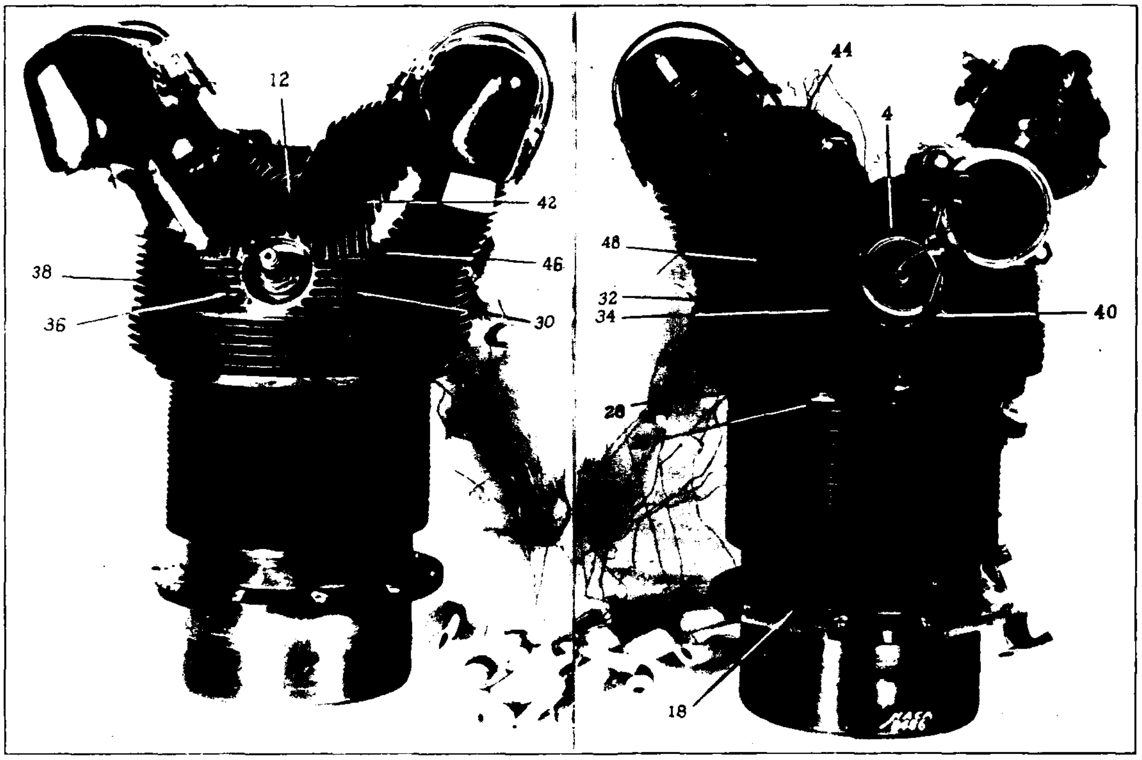
Engine.—The engine used for these tests is a 14-cylinder 2-row radial, designated a GR-1535 Pratt & Whitney Wasp, Jr. The engine has an over-all diameter of 43⅞ inches. It is rated at 700 horsepower at 2,500 r. p. m., has a compression ratio of 6.5, and is equipped with a geared centrifugal supercharger that operates at eight times engine speed. This supercharger will maintain a manifold pressure of approximately 33 inches of mercury absolute at sea level when the engine is operating at 2,600 r. p. m. The propeller is driven through a 3:2 reduction gear. For the greater part of the investigation the engine was equipped with a 2-blade Smith controllable propeller having a diameter of 10 feet; the remaining tests were made with a 3-blade adjustable propeller having a diameter of 10 feet 6 inches.

The rear-row cylinders on this engine have more finning around the exhaust ports than the cylinders in the front row (fig. 1). Intercylinder baffles limit the amount of cooling air flowing past the cylinders. These baffles, as shown in figure 2, fit closely to the cylinders and are supplemented by pieces that fit closely to the fins at the top of the cylinder and extend outward to an N. A. C. A. cowling ring, forming a wall blocking off the area between the cowling and the engine. These baffles keep the air close to the cylinder and guide it to the rear of the cylinder (reference 1).

In these tests the oil radiator was modified so that water instead of air was used for carrying the heat



Front view. Cylinder 3 Rear view.



Front view. Cylinder 4. Rear view.

FIGURE 1.—Comparative finning on the rear-row (cylinder 3) and the front row (cylinder 4) cylinders and also the location of thermocouples.

away from the oil. This change was necessary in order to obtain sufficient cooling when operating at high power output with low air speeds.

Airplane.—The engine was mounted in a Vought XO4U-2 airplane, a 2-place observation airplane of conventional design with a maximum speed of 185 miles per hour.

Full-scale tunnel.—All the tests except a few high-speed flight tests were made in the Committee's full-scale tunnel (reference 2). This tunnel has a 30- by 60-foot jet and a maximum air speed of approximately 120 miles per hour. Figure 3 shows the airplane mounted on the balance in the full-scale tunnel.

Instruments.—Iron-constantan thermocouples connected to two Brown recording pyrometers were used for measuring the cylinder temperatures. The thermocouples were made from 0.016-inch diameter enameled and silk-covered wire. The thermocouples were peened to the cylinder heads and electrically spot-welded to the steel barrels. The location of the 47 thermocouples used is given in table I and figure 1. These thermocouples were located as shown in order to obtain the difference in temperature between front- and rear-row cylinders, the maximum temperature on a front- and a rear-row cylinder, and an indication of temperature difference between several cylinders in each row.

TABLE I.—LOCATION OF TERMOCOUPLES

Thermocouple	On cylinder [1]	Corresponding thermocouple on cylinder 3 [2]
1	1	3
2	2	3
5	5	3
6	6	3
7	7	3
8	8	3
9	9	3
10	10	3
13	5	11
14	6	11
15	7	11
16	8	11
19	5	17
20	6	17
21	7	17
22	8	17
23	Front section of crankcase.	
24	Blank, for synchronizing records.	

[1] Cylinders are numbered in accordance with the customary practice. (See fig. 2 (b).)

[2] For location of thermocouples on cylinders 3 and 4 see fig. 1.

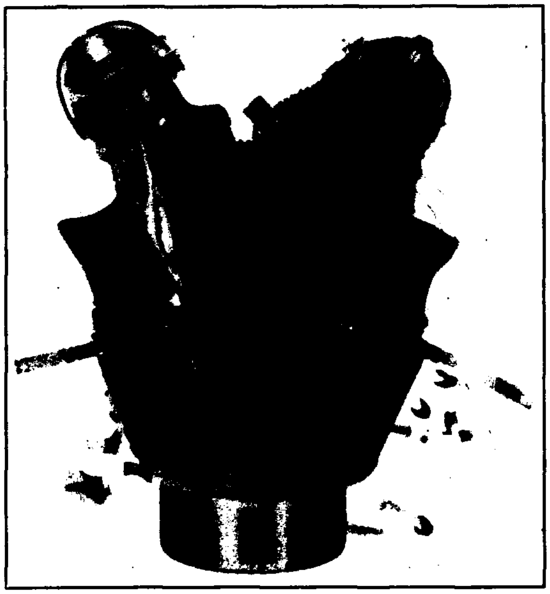
In addition to the cylinder-temperature measurements the following temperature measurements were obtained:

Oil in.
Oil out.
Carburetor air.
Air stream.
Cold junction of thermocouples.
Accessory compartment.
Oil radiator, water in.
Oil radiator, water out.

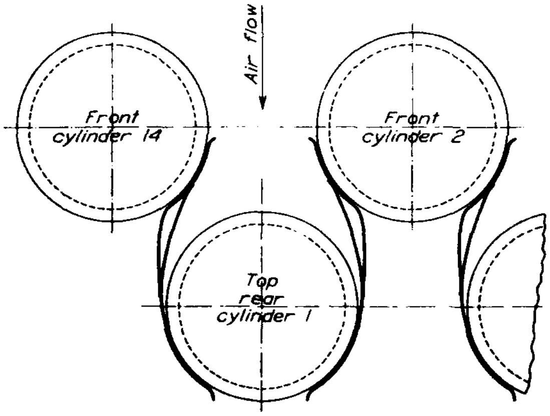
Electrical-resistance thermometers were used for measuring the first six temperatures and vapor-pressure thermometers for those of the oil radiator.

The engine speed was measured with an electrical tachometer and the manifold pressure with a mercury manometer. The wind-tunnel air speed was obtained from a static-plate calibration of the tunnel for each test condition. Fuel-consumption measurements were obtained with a calibrated displacement-type fuel flowmeter. The water passing through the air passages of the oil radiator was measured with a calibrated water meter.

With the exception of the static-plate manometer and the water-in and water-out thermometers in the oil radiator all instruments were located in the scale room directly below the airplane.



(a) Baffles assembled on a rear-row cylinder.



(b) Plan view of intercylinder baffles.

FIGURE 2.—Arrangement of intercylinder baffles on Pratt & Whitney GR-1535 2-row radial engine.

METHOD OF TESTING

The effect on the cylinder temperatures of operating at several engine speeds from 1,700 to 2,500 r. p. m. was investigated for full-throttle conditions at air speeds of 85, 102, and 119 miles per hour. Tests were also made at several engine speeds from 1,500 to 2,500 r. p. m. with manifold pressures of approximately 29, 24, and 20 inches of mercury absolute and at an air speed of 116 miles per hour. For each of these runs the desired engine speed was obtained at each air-speed and manifold-pressure condition by varying the pitch of the propeller.

The effect of engine speed on the cylinder temperatures for a constant brake horsepower and a constant air speed of 119 miles per hour was determined. The power was maintained constant by changing the propeller pitch and the manifold pressure. The manifold pressure required to give constant power when the engine speed was varied was obtained from the calibration curves for the engine. Although engine manufacturers have limited the temperature of the rear spark plug boss to 500° F. for satisfactory cooling, long engine life, and reliability, higher temperatures were tolerated in some runs in order to extend the range of the tests.

Four full-throttle runs were made at an engine speed of 2,500 r. p. m. and at an air speed of 120 miles per hour to determine the variation in cylinder temperature with mixture ratio by varying the rate of fuel flow. The lowest rate was determined by the maximum cylinder-head temperature, which was limited to 600° F., and by the general operation and power output of the engine. The maximum rate was with the mixture control set full rich.

The difference in cylinder temperatures obtained with 2-blade and 3-blade propellers was determined for full-throttle operation at engine speeds of 2,000 and 2,100 r. p. m. and at air speeds of 85 and 120 miles per hour, respectively.

FIGURE 3.—The XO4C-2 airplane mounted in the full-scale tunnel ready for test.

The effect of the attitude of the airplane on the cylinder temperatures was determined for four different angles of attack (based on the thrust axis): −4°, 0°, 4°, and 8°. These tests were made at an air speed of 100 miles per hour, at an engine speed of 2,100 r. p. m., and at full-open throttle.

The lubricating oil used in these tests conformed to the Navy specifications for a 3120 oil. Gasoline conforming to Army specifications Y-3557-G and having an octane number of 87 was used in most of the investigation. For the most severe conditions sufficient ethyl fluid was added to the gasoline to increase the octane number to 92.

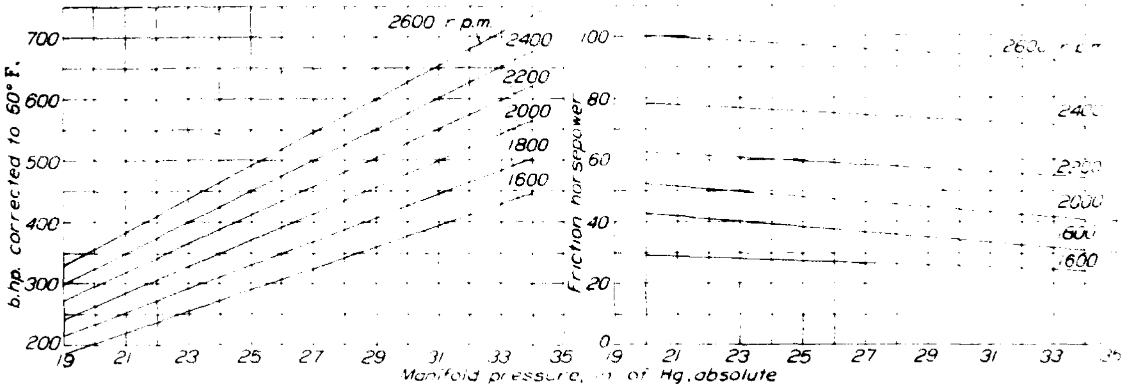


FIGURE 4.—Calibration curves showing brake and friction horsepower at various engine speeds and manifold pressures.

A few runs were also made at what might be called "normal" operation with a fixed-pitch propeller. The propeller pitch was set so that 2,500 r. p. m. could be obtained at an air speed of approximately 120 miles per hour when operating at full-open throttle. With this pitch setting, performance measurements were obtained at full-open throttle for air speeds of 80, 100, and 120 miles per hour. A similar series of runs was made with the propeller pitch set to give a full-throttle engine speed of 2,150 r. p. m. at an air speed of 120 miles per hour. Test runs were then made with this fixed-pitch setting when operating at full-open throttle at air speeds of 60, 80, 100, and 120 miles per hour.

COMPUTATIONS

Engine power.—The engine was calibrated before and after these cooling tests by the Research Division of the United Aircraft and Transportation Corporation (reference 3). The calibration curves of friction and brake horsepower for various speeds and manifold pressures are shown in figures 4 and 5. In the preparation of these curves the power developed was corrected to a standard atmosphere (29.92 inches of mercury pressure and 60° F. temperature).

The power developed was obtained from the calibration curves for the observed manifold pressure and engine speed. A correction was then applied to the power obtained from the calibration curves for the difference in carburetor-air temperature during the calibration and during the test according to the relation

$$\text{Observed b. hp.} = \text{b. hp. (at 60° F.)} \sqrt{\frac{T_s+460}{T_0+460}}$$

where

T_0, observed air temperature at the carburetor.

T_s, standard air temperature at the carburetor (60° F.).

Cylinder temperatures.—The pyrometer readings of cylinder temperatures were corrected for instrument calibration and cold-junction variation and were converted to a standard cooling-air temperature of 70° F.

Air speed.—The observed air speed was corrected to an air speed at 29.92 inches of mercury and 70° F. from pressure and temperature measurements according to the relation

$$V_s = \frac{V_0\rho_0}{\rho_s}$$

where

V_0, observed air speed.

V_s, air speed at 29.92 inches of mercury pressure and 70° F.

ρ_0, observed density.

ρ_s, standard density.

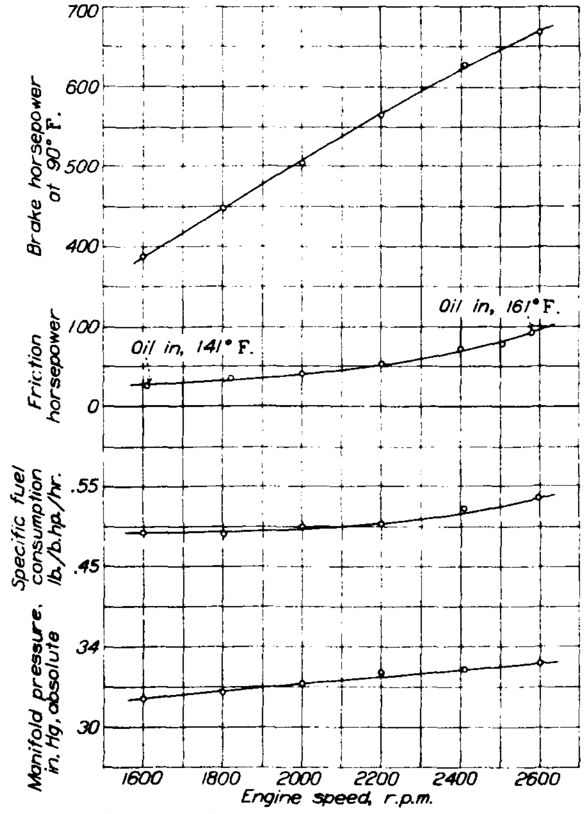


FIGURE 5.—Full-throttle calibration of GR-1535 engine.

Heat loss to the oil. The heat loss to the oil was calculated from the quantity and increase in temperature of the water flowing through the oil cooler.

Fuel consumption. The specific fuel consumption was calculated from the fuel flow, observed horsepower, and density of the fuel.

RESULTS AND DISCUSSION

Effect of specific fuel consumption. The curves in figure 6 (a) for full throttle show that the leaning of a very rich mixture so as to obtain a reduction in specific fuel consumption of 0.10 pound per brake horsepower per hour resulted in only a small increase in cylinder temperatures; whereas the leaning of a lean mixture so as to obtain the same reduction in specific fuel consumption resulted in a large increase in cylinder temperatures. The temperatures at different points on the same cylinder varied consistently with the mixture strength; those that are high showed the greatest variation. As a lean mixture burns slowly the cylinder walls are exposed to burning gases during a large part of the expansion stroke; with a rich mixture some of the heat is carried out through the exhaust by the excess fuel.

A comparison of the curves of temperature variation with specific fuel consumption for several cylinders (fig. 6(b)) shows that the temperature of each cylinder did not vary the same amount when the mixture strength was changed. The amount of this variation depends upon how much difference there is in the mixture ratio of the charge delivered to each cylinder. Temperature differences between cylinders are often attributed to poor distribution or to nonuniform cooling of the cylinders because of their location with respect to other engine parts. These curves show that temperature differences between cylinders can be definitely attributed to poor distribution only after a sufficient number of runs have been made to establish the curve of cylinder temperature against specific fuel consumption. The cylinders that are operating on a lean mixture will show the greatest variation in temperature with change in mixture strength. On the basis of these curves the variation in mixture strength for different cylinders is estimated to be at least 10 percent.

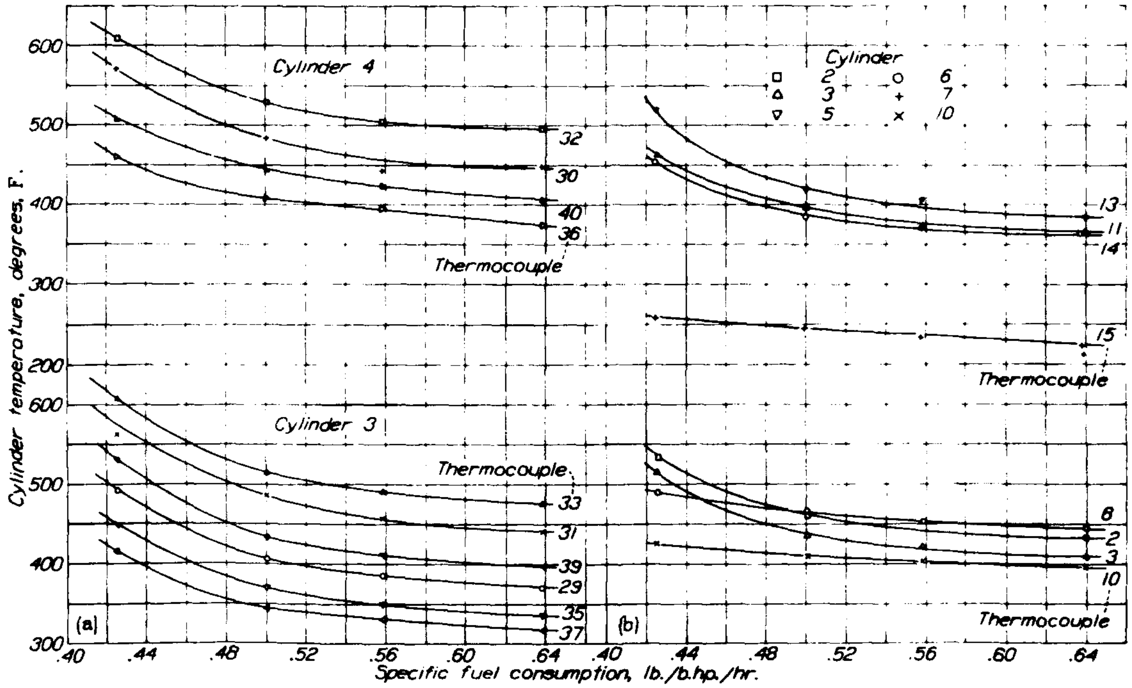
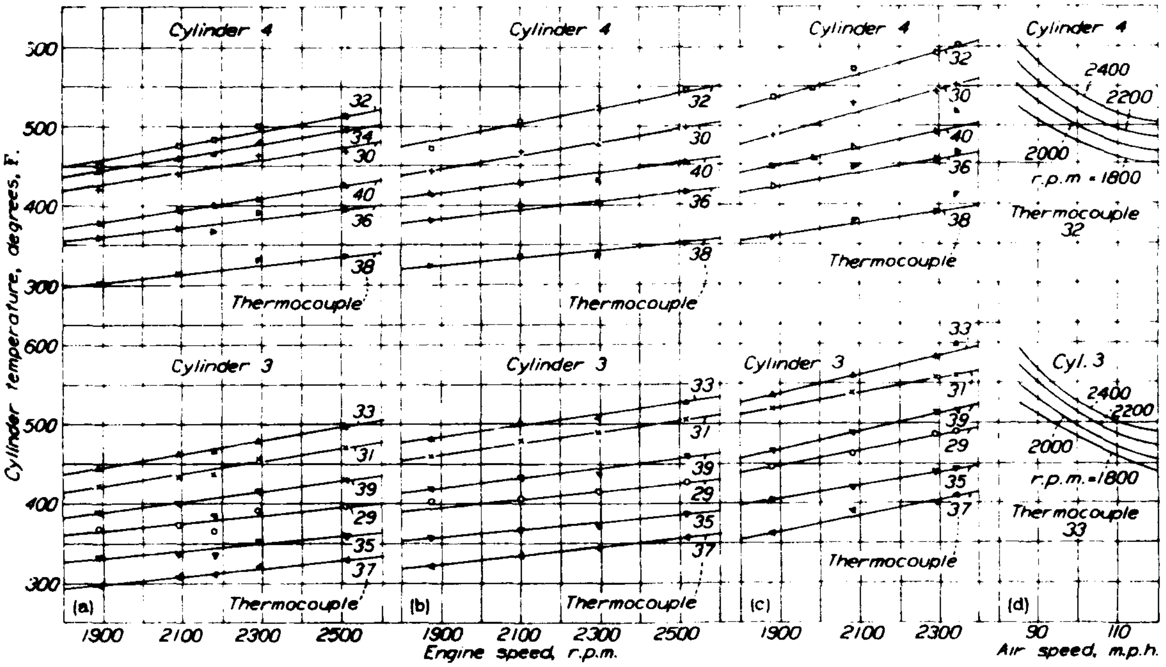


FIGURE 6.—Effect of specific fuel consumption at full throttle on the cylinder temperatures. In these tests the horsepower varied from 675 to 695, the engine speed from 2,427 to 2,498 r. p. m.; the manifold pressure from 33.33 to 33.61 in. Hg, absolute, and the air speed from 116.2 to 119.2 m. p. h.

Effect of engine speed and air speed when operating at full throttle. The cylinder temperatures obtained when operating full throttle at engine speeds between 1,800 and 2,600 r. p. m. and at average air speeds of 85, 102, and 119 miles per hour are shown in figure 7. These temperature measurements from the 6 thermocouples on cylinder 4 and from the 6 on cylinder 3 are only a part of the temperature data obtained; they have been selected after comparison with other temperatures observed as a fair representation of all engine temperatures. When the engine speed was increased from 1,800 to 2,600 r. p. m., the brake horsepower was increased 50 percent (fig. 5) and the indicated horsepower 59 percent; whereas the difference in temperature between the cylinder and the air increased 15 to 24 percent (fig. 7).

It may be well to state that these results have been substantiated in laboratory tests of a single-cylinder air-cooled engine. The much more rapid increase of the engine power than of the cylinder temperatures indicates that considerably more power can be obtained from an air-cooled cylinder with small improvements in the finning. The specific fuel consumption and the manifold pressures increased slightly in these tests. The increase in specific fuel consumption caused by increasing the engine speed from 1,800 to 2,600 r. p. m. resulted in a reduction in cylinder temperature of approximately 10° F.; whereas the increase in manifold pressure would result in an increase in cylinder temperature of less than 5° F.



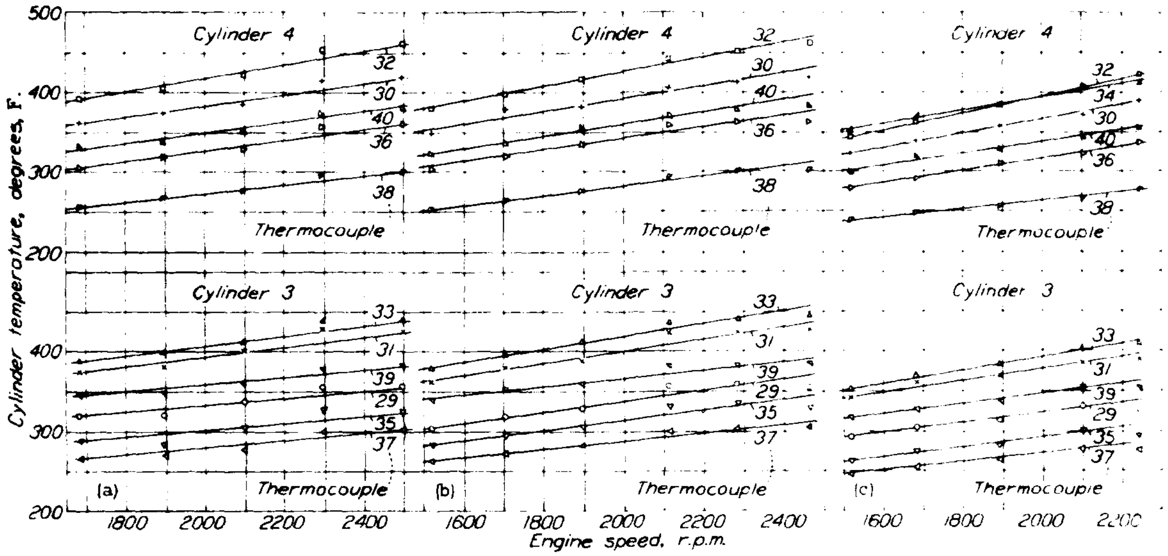
	Specific fuel consumption		Manifold pressure		Air speed	
	lb./b.hp./hr.		*in. Hg, absolute*		*m. p. h.*	
(a)	0.610	0.646	32.24	33.17	118.4	120.0
(b)	.596	.645	32.17	33.11	101.4	102.7
(c)	.590	.611	32.30	33.60	84.0	86.2
(d)	Cross-plot of (a), (b), and (c)					

FIGURE 7.—Effect of engine speed and air speed on cylinder temperatures when operating at full throttle.

The results shown in figure 7 closely simulate those obtainable in full-throttle climbs at higher engine speeds. At air speeds of 85 to 90 miles per hour, the best climbing range for this airplane, the highest cylinder-head temperatures at 2,500 r. p. m. were more than 600° F., which is appreciably higher than what would be considered permissible for long life and reliability. The results indicate that this engine as installed in the XO4U-2 airplane can be operated at a full-throttle speed of 2,500 r. p. m. without exceeding the safe cylinder-head operating temperature (500° F.), provided that the speed of the airplane is 120 miles per hour and that the mass flow is equal to that of cooling air at 70° F. and at standard sea-level density. Without a controllable propeller these high engine speeds could not be obtained in climb unless the propeller pitch were set so low that level flight at full-open throttle would be impossible without excessive engine speeds. Flight tests conducted elsewhere on this airplane indicate that, when an adjustable propeller having the best setting for high speeds is used, the engine speed in climb will be so low that the safe operating temperature is not exceeded at air speeds of 80 to 90 miles per hour.

Flight tests conducted at air speeds higher than those obtainable in the tunnel showed that the cooling was satisfactory for these conditions. In full-throttle climbs at high engine speeds, however, the cylinder temperatures, like those in the tunnel, were high. No attempt was made to reduce the temperatures obtained in flight to the same standard because the magnitude of the various corrections is *not sufficiently* well established *to justify comparison.*

Effect of engine speed when operating at various throttle settings. The cylinder temperatures obtained when operating at different throttle settings at various engine speeds and at approximately constant air speed are shown in figure 8. These curves show that, regardless of the amount of throttling or of the manifold pressure at which the engine operates, a certain percentage increase in power due to increase in engine speed will, for each condition, result in approximately the same percentage increase in temperature. For example, when operating at a manifold pressure of 19.2 inches of mercury an increase in engine speed sufficient to cause a 50 percent increase in brake horsepower will result in an average increase in the temperature difference between the cooling air and the cylinder of 21 percent on the front-row cylinder and of 17 percent on the rear row. At a manifold pressure of 28.44 inches of mercury absolute a 50 percent increase in power will result in an average increase in cylinder temperature difference of 22 percent for cylinder 4 and an increase of 15 percent for cylinder 3. The largest percentage increase in temperature difference in each case is for the front-row cylinders, which have the least amount of finning around the head.



	Specific fuel consumption	Manifold pressure	Air speed
	lb./b.hp./hr.	*in. Hg, absolute*	*m. p. h.*
(a)	0.614–0.654	28.36–28.53	116.0–117.4
(b)	.563–.647	23.67–23.91	114.5–115.7
(c)	.607–.652	19.15–19.27	115.8–117.6

FIGURE 8.—Cylinder temperatures obtained with varying manifold pressures and engine speeds when the air speed is practically constant.

The curves in figure 9 show the relation between the average cylinder temperatures and the brake and indicated horsepower for two conditions, one with constant speed and varying manifold pressure and the other with varying speed and constant manifold pressure. The average temperature for thermocouples 29, 31, 33, 35, 37, and 39 on cylinder 3 were used in the preparation of these curves. It is interesting to note that increasing the brake horsepower by increasing the speed results in a slightly greater rate of change in temperature than is obtained by increasing the manifold pressure. On an indicated-power basis the temperatures for each of the two conditions of varying the power fall on the same straight line. Within the range of these tests it is apparent that nothing is to be gained in reduced cylinder temperatures by increasing either function of the power in preference to the other.

Effect of engine speed when operating at approximately constant power.—The results in figure 10 show that the cylinder temperatures are not influenced by the engine speed or pitch setting provided that the power and other conditions remain constant. In these tests the brake horsepower decreased from 530 to 503 and the indicated horsepower increased from 570 to 600 when the engine speed was increased from 2,000 to 2,600 r. p. m. It has been shown earlier that a 5 to 6 percent variation in engine power would cause a change of approximately 2 percent in the cylinder temperatures. The slightly higher temperatures obtained at a speed of 2,000 r. p. m. were mostly due to a low specific fuel consumption, the specific fuel consumption being

0.606 pound per brake horsepower per hour for this run and more than 0.638 pound per brake horsepower per hour for the other runs. The difference in specific fuel consumption would cause a variation in temperature of from 10° to 15° F.

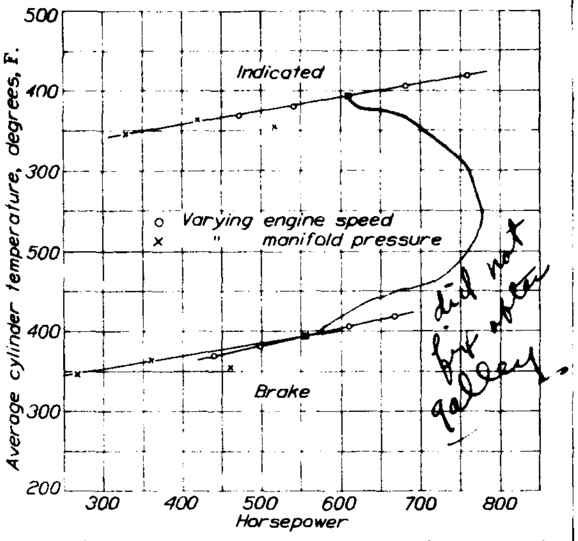


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FIGURE 9.—Effect on cylinder temperatures of increasing power by increasing either engine speed or manifold pressure.

Effect of changing air speed when propeller pitch is constant.—The two sets of runs (fig. 11) in which the propeller pitch was set to give full-throttle engine speeds of 2,500 and 2,150 r. p. m. showed that when the air speed was reduced the cylinder temperatures increased to exceed the safe operating temperature at the lower air speed.

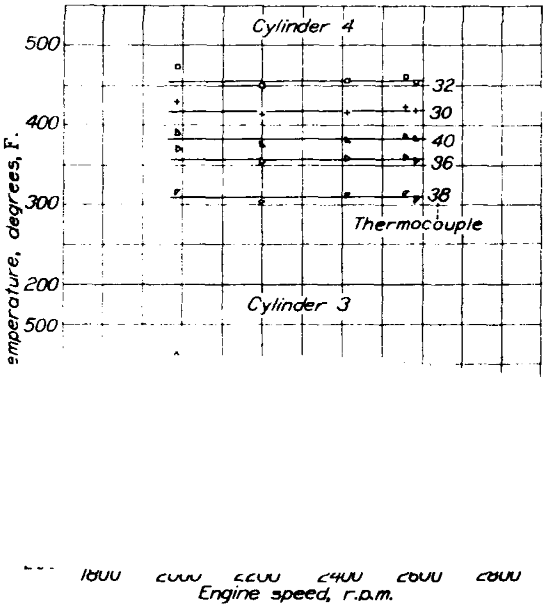

FIGURE 10.—Effect on cylinder temperatures of operating at various engine speeds when the power and the air speed are constant. In these tests the brake horsepower varied from 503 to 532; the specific fuel consumption from 0.606 to 0.651 lb. per b.hp. per hr.; the air speed from 118.0 to 119.3 m. p. h.; and the manifold pressure from 25.40 to 33.44 in. Hg, absolute.

Heat loss to lubricating oil.—The curves in figure 12 show the ratio between the heat loss to the oil and the heat going into indicated power at different engine speeds when operating at a constant engine power of 530 brake horsepower and when operating with the engine power varying from 498 to 692 brake horsepower. Increasing the speed when the power was held constant resulted in an increasing amount of heat being carried away from the oil. The total quantity of heat carried away with varying power may appear to be less than with constant power but such is not the case, however, for the lower curve is based on a higher brake horsepower.

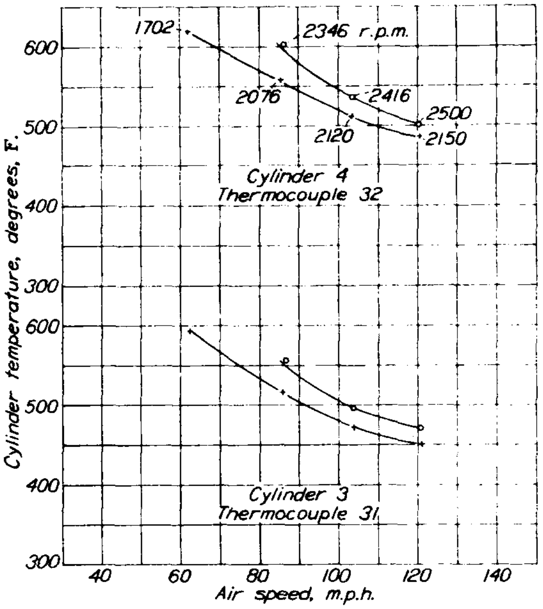

FIGURE 11.—Effect on cylinder temperature of changing air speed when propeller pitch is constant.

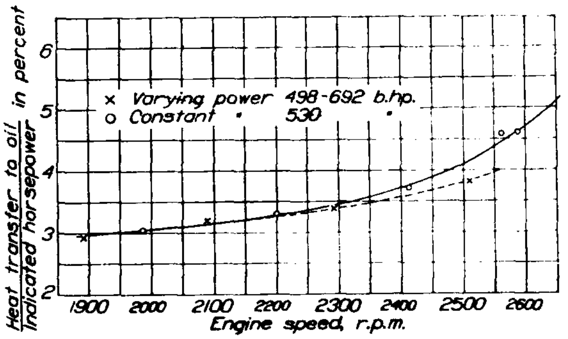

FIGURE 12.—Heat loss to the oil.

When the mixture is leaned, the heat loss to the oil increased from approximately 4 to 6 percent of the heat going into indicated power because of the increase in temperature of the cylinder walls.

The heat loss to the oil in these tests was higher than would be obtained in regular service because the cylinder temperature in many runs exceeded the specified service temperatures. Recent tests on this engine by the Bureau of Aeronautics, Navy Department, gave a heat loss to the oil equal to 1.72 percent of the heat going into useful work.

In the most severe of these tests excessive oil-out and accessory-compartment temperatures were obtained. When the mixture was leaned, the accessory-compartment temperatures reached a maximum of 220° F. and the oil-out, 200° F. In all other tests the oil-out and accessory-compartment temperatures varied between 150° and 190° F. depending on power output and air speed.

Effect of angle of attack.—Increasing the angle of attack of the airplane (based on thrust axis) from −4° to 8°, which includes the high-speed and climbing attitude at full throttle, caused the temperature of the top cylinders in the front row to increase 15° to 20° F. and the temperature of the bottom cylinders in the front row to decrease the same amount. The other cylinders did not show any consistent change with angle of attack. The change in temperature on the rear-row cylinders was slightly less than on the front row. The results indicate that a reduction in temperature can be obtained by setting the fins at a slight angle with respect to the air stream.

Cylinder temperatures obtained with 2-blade and 3-blade propellers.—These tests showed that at low air speeds the use of 3-blade propellers resulted in lower cylinder temperatures than that of 2-blade propellers. At an air speed of approximately 120 miles per hour the average temperature for all thermocouples on the cylinders was practically the same with each propeller; whereas at an air speed of 80 miles per hour the average temperature for all thermocouples was 17° F. lower when using a 3-blade propeller.

CONCLUSIONS

The results of this investigation show that with a GR-1535 engine installed in a Vought XO4U-2 airplane:

1. When operating at full-open throttle at an engine speed of 2,500 r. p. m., an air speed of 120 miles per hour must be maintained for satisfactory cooling (500° F. cylinder-head temperature) with air at a pressure of 29.92 inches of mercury and a temperature of 70° F.
2. Increasing the brake horsepower 50 percent resulted in a 15 to 24 percent increase in the temperature difference between the cooling surface and the cooling air.
3. The same percentage change in temperature difference between the cooling air and the cooling surface was obtained for a given change in power when the manifold pressure was varied as when the engine speed was varied.
4. Increasing the air speed from 60 to 120 miles per hour resulted in a decrease of 17 percent in the average difference in temperature between the cylinder and the cooling air.
5. The heat loss to the oil under these particular test conditions was equal to from 3 to 6 percent of the heat going into indicated power depending on the engine speed and fuel-air ratio.
6. The amount the temperature of different cylinders changes when the mixture strength is varied was found to be a good indication of mixture distribution in the engine.
7. The effect of the attitude of the airplane on the cylinder temperatures was small and slightly dependent on location of the cylinder.
8. There was practically no difference in the cylinder temperatures obtained with either 2-blade or 3-blade propellers at an air speed of 120 miles per hour; at an air speed of 80 miles per hour the average cylinder temperature for all the thermocouples was 17° F. lower with the 3-blade propeller.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *December 4, 1934.*

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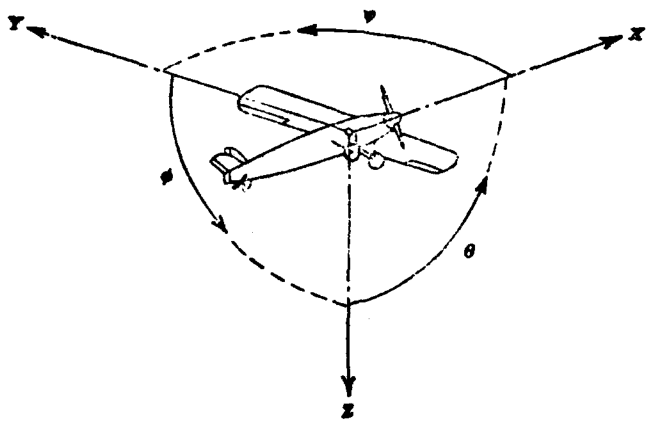

Positive directions of axes and angles (forces and moments) are shown by arrows

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) $C_m = \frac{M}{qcS}$ (pitching) $C_n = \frac{N}{qbS}$ (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 $= \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

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.