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COWLING AND COOLING TESTS OF A FLEETWINGS MODEL 33 AIRPLANE IN FLIGHT

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MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

COWLING AND COOLING TESTS OF A FLEETWINGS MODEL 33 AIRPLANE IN FLIGHT

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SUMMARY

The cooling of a Franklin 6-AC-298 horizontally opposed cylinder air-cooled engine installed in a Fleetwings model 33 trainer has been investigated in flight at the request of the Army Air Forces, Materiel Command. The present report was written in response to several inquiries as to the cooling characteristics of this type of engine.

The cowling on the airplane as received did not provide satisfactory cooling. The cowling was altered in several steps and cylinder baffles installed in an effort to improve the cooling of the engine and tests were conducted over a wide range of engine, airplane, and cooling conditions from sea level to 10,000 feet altitude. Ground, climb, and level-flight tests were made. A complete description of the cowling and baffle alterations is given in the report.

The results of the tests showed that with the cowling inlet relocated as in the new design behind the active part of the propeller the highest total pressure in the inlet was about $0.8q_o$ greater than that in the free stream. Available pressure differences across the cowling, total pressure at the cowling inlet minus static pressure at the cowling exit of $2.1q_o$ with a 30° flap angle and $1.8q_o$ with a flap angle of 0°, were obtained at high values of propeller-power coefficient. At low values of propeller-power coefficient these values decreased to 1.8 and 1.5, respectively. The loss in total pressure from the cowling inlet to the upstream face of the engine was roughly $0.2q_o$ and the loss from the downstream side of the engine to the

cowling exit was negligible. Cooling was shown to be adequate in level flight and probably adequate in climb and on the ground. No definite conclusion could be made for the latter two conditions because the tests were terminated due to unsatisfactory engine operation and the data were therefore limited. The cooling-pressure drops were as high as could be obtained without auxiliary boosting such as use of a fan. Further improvement in cooling of the subject power-plant installation requires some means other than cowling design.

INTRODUCTION

The cooling of a Franklin 6-AC-298 horizontally opposed cylinder air-cooled engine installed in a Fleetwings model 33 trainer was investigated in flight at the Langley Memorial Aeronautical Laboratory during November and December 1941. This investigation was undertaken at the request of the Army Air Forces, Materiel Command. Due to higher priority of other work no final report was written of the results at the completion of the tests. The present report has been written in response to several recent inquiries as to the cooling characteristics of this type of engine and installation.

The original cowling for the 6-AC-298 engine in the Fleetwings airplane using inlets above the center line of the cylinders, having no baffles, and discharging the air from below the cylinders through side and bottom outlets was reported by the contractor as providing unsatisfactory cooling. The type of cowling used in the original Fleetwings installation is unsatisfactory from an aerodynamic standpoint. The inlet-air passages are small and the high-velocity flow undoubtedly causes high pressure losses. The unbaffled spaces between cylinders allow a large flow of air that accomplishes no cooling and the air that does flow through the fin passages separates from the cylinder at the sides and fails to reach the downstream side of the cylinder. The ram that can be obtained in the inlets as originally located is also much lower than can be obtained with a single inlet below the propeller-thrust axis and behind a more active part of the propeller blades.

The object of this report is to describe a new cowling and cylinder baffles designed and constructed under the direction of the NACA with the object of obtaining the maximum possible cooling and to present results of flight tests made to determine the cooling obtained. The flight tests were conducted by personnel of the Fleetwings company under the direction of Mr. Carl DeGanahl. Tests were made over a large range of engine and flight conditions from altitudes of 1000 to 10,000 feet. The instrumentation used to obtain the data was limited due to the size of the airplane and the time available for the testing. Although the instrumentation is not considered adequate for obtaining the best results for cooling tests, the results are considered satisfactory from the standpoint of providing an aid to designers of airplanes using this type of engine.

SYMBOLS

A	flow area at various stations, feet^2
a	velocity of sound in air $\left(49.2\sqrt{T_a + 460}\right)$, feet per second
C	a constant
D	propeller diameter, feet
d	engine-piston displacement, inches^2
F_c	compressibility factor, $\left(1 + \frac{M^2}{4} + \frac{M^4}{40} \ldots\right)$
g	acceleration due to gravity, feet per second per second
H	total pressure, pounds per foot^2 or inches of water
I_{T_a}	indicated horsepower of engine at temperature, T_a
I_{60}	indicated horsepower of engine at temperature of 60° F
K	a constant
M	Mach number, V/a

m	a constant
N	engine speed, rpm
n'	a constant
P	brake power of engine, foot-pounds per second
P_c	propeller-power coefficient $\left(P/\rho_o V_o^3 D^2\right)$
p	static pressure, pounds per foot^2
p_b	back pressure on engine, inches of mercury absolute
p_m	manifold pressure, inches of mercury absolute
q	dynamic pressure, pounds per foot^2
q_c	indicated dynamic pressure, pounds per foot^2
T	propeller thrust, pounds
T_a	cooling-air and carburetor-air temperature, $^\circ$F
T_b	average cylinder-barrel temperature of engine, $^\circ$F
T_c	thrust coefficient $\left(T/\rho_o V_o^2 D^2\right)$
T_g	effective gas temperature, $^\circ$F
T_{g_o}	effective-gas temperature at 0° F carburetor-air temperature, $^\circ$F
T_h	average cylinder-head temperature of engine, $^\circ$F
T_x	cylinder-wall temperature, $^\circ$F
V	velocity, feet per second
W	weight of cooling air flowing over engine, pounds per hour
x	a constant
ΔH	cooling-air pressure drop across cylinder heads or cylinder barrels of engine, inches of water, $(H_2 - H_3)$

Δt_a	temperature rise of cooling air across engine, $^{\circ}F$
α	angle of attack of airplane
Δ	denotes increment
η	propeller efficiency (TV_o/P)
ρ	density of cooling air, slugs per cubic foot
ρ_s	standard air density, slugs per cubic foot (0.002378)
$\rho_{1,2}$	mean density of air between stations 1 and 2, slugs per cubic foot
$\rho_{2,3}$	mean density of air between stations 2 and 3, slugs per cubic foot
$\rho_{3,4}$	mean density of air between stations 3 and 4, slugs per cubic foot
σ_2	(ρ_2/ρ_s)
fmep	friction mean effective pressure, pounds per inch^2
fhp	friction horsepower

Subscripts:

o	free-stream condition	See figure 16 for station positions.
1	station at duct or cowling entrance	
2	station at face of engine	
3	station at rear of engine	
4	station at flap hinge	
5	station at flap exit	

These subscripts are used to define H, p, A, q, and ρ at the various stations in the duct system.

AIRPLANE ALTERATIONS

Cowling and Installation Changes

The details of the original and redesigned power-plant installations are summarized in table I. Figures 1 and 2 show the airplane, which is a low-wing two-place monoplane with the original cowling and power-plant installation. The airplane was equipped with wing flaps and a two-blade fixed-pitch propeller, design 76FA54. The power plant was a Franklin horizontally oppossed six-cylinder 6-AC-298 unsupercharged air-cooled engine rated 130 brake horsepower at 2550 rpm at sea level with a manifold pressure of 29.92 inches of mercury and a carburetor-air temperature of 60° F. The compression ratio, bore, and stroke of the engine are 7:1, 4.25 inches, and 3.5 inches, respectively. The airplane was equipped with dual Eismann ignition and with two Marvel carburetors. The carburetors were equipped with manual mixture control.

In the original installation, configuration A of table I, the cooling air entered two small openings in the nose of the cowling behind the blade shanks (see figs. 1 and 2), passed over the cylinders from top to bottom, and then out openings at the sides and bottom of the cowling below the engine. The reservoir between the tops of the cylinders and the top surface of the cowling was not very large and there was a chance of having some velocity head in this space which would cause poor cooling-pressure distribution from cylinder to cylinder. The space between the bottom of the cylinders and the bottom surface of the cowling was crowded with engine accessories, carburetor heating ducts, and two oil coolers which interfered with the passage of the cooling air from the cowling. Further details of configuration A are given in table I.

The first step in improving the cooling of the engine was to redesign the cowling. The altered cowling, as shown in diagrammatic form in figure 3, was designed at this Laboratory in cooperation with representatives of the Fleetwings Company to take the cooling air and carburetor air in one large opening in the lower half of the cowling nose and discharge the cooling air at the top rear of the cowl skirt. This type of top outlet was considered satisfactory on this particular power-plant installation as it was being developed for a pilotless airplane. For a normal arrangement outlets should be carried around to the sides of the cowling to avoid oil from the engine impairing the pilot's vision through the windshield. The direction of air flow across the engine was reversed, as compared to the original installation, because the space below the engine was much larger than that above the engine thus forming a large pressure chamber below the engine in which the velocity of the air was small. The pressure distribution across the cylinders would therefore be more uniform that if the air was discharged from a small space as in the original installation. The inlet opening was located as low as possible in the cowling nose in order to take advantage of a possible increase in front pressure due to the opening being behind the airfoil section of the propeller. Views of the cowling outline for configuration A (see table I) and the inlet are shown in figure 4 and a close-up of the inlet in figure 5. A close-up view of the compartment below the engine with the new installation is given in figure 6.

The size of the inlet opening was determined from the estimated quantity of cooling air and carburetor air required by an engine of a little greater horsepower than the rated power of the engine in the airplane, because of possible future increases in power, and the cooling air required by the oil coolers at 12,000 feet altitude. The design was based on the assumption that the velocity in the inlet would be limited to one-half the velocity of the airplane at that altitude. This gave an area of 115 square inches. The size of the cowling exit for adequate cooling could not be determined accurately because the cooling characteristics of the engine were unknown. For this reason three sizes of exit opening were tested: 41 (configuration B), 75 (configurations C, D, E, F, and G), and 135 (configuration H) square inches. Configuration H also included a fixed flap (figs. 3 and 7) set at a 30° angle to the cowling surface. Extreme care was taken to seal the compartment below the engine from that above the engine.

In addition to altering the cowling the oil coolers below the engine were replaced with a single large cooler slung below the fuselage just aft of the cowling skirt. Although the oil cooler is an important part of a power-plant installation, the present tests only involved the cooling of the engine itself. The cooler installation was only a temporary means of cooling the oil during the tests. Other clean-up of the space below the engine was made including the installation of a new carburetor duct system as shown in figures 3 and 6. The new carburetor duct system was arranged such that cold air or hot air could be taken into the engine by operating a linkage C (fig. 3) which held either free-swinging door A or B shut. Cold air was taken in a duct at the inlet opening of the cowling. (See figs. 3, 5, and 6.) The hot air was obtained by connecting ducts to shrouds around the exhaust pipes (figs. 3 and 6), the inlets to the shrouds being open to the chamber below the engine. The duct system was equipped with a backfire arrangement such that when a backfire occurred the free-swinging doors A and B would close against door stops and a backfire door E (fig. 3) would open. The use of this system cleaned up the space below the engine appreciably.

Cylinder Baffles

The engine was not equipped with cylinder baffles in the original installation (configuration A, table I). A set of baffles was made, as shown in figure 8 and diagrammatically in figures 3 and 9, which fitted tight against the fin tips at the rear of the cylinders, the space between the cylinders being closed to the passage of air by the baffles. The exit area of the baffles was made 1.6 times the free-flow area between the fins. These baffles were used with all of the altered cowling configurations. Several baffle modifications were tested based on the results of the tests with the cylinder baffles. These modifications included spark-plug baffles, a blast tube, and baffle ducts. The spark-plug baffles were plates placed over the large cut-outs around the spark plugs in the original cylinder baffles (fig. 10(a)), the idea being to keep high-velocity air in contact with the cylinder for a greater distance around the cylinder. The blast tube directed cold air on to the spark plug. The baffle ducts (fig. 10(b)) carried air direct from the pressure chamber below the engine to the hot sides of the cylinder heads. Further details as on what cylinders the baffle modifications were used and with what cowling configuration are given in table I.

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COOLING TESTS

Instrumentation

Temperatures of the cylinders were measured by 36 thermocouples located as shown in the sketch on figure 11. Six of the thermocouples were gasket-type thermocouples under the spark-plug flange, six were embedded thermocouples in the barrel flanges, and the other 24 were embedded or spot-welded thermocouples evenly distributed over the front and rear of the barrels and heads of the cylinders. Two sets of three thermocouples, each set connected in series, were used to measure the temperature of the cooling air issuing from the baffles, one set on each side of the engine. Each thermocouple of a set was located directly behind a cylinder as shown in figure 8. A thermocouple was located on the antenna strut shown in figure 4. The temperature recorded by this thermocouple was used for the inlet-cowling air and the carburetor-air temperatures. A thermocouple was placed in the carburetor duct but the temperature recorded was so close to the antenna-strut temperature that the latter was used for the carburetor temperature as noted. Thermocouples were also used to record the temperatures of the magnetos, accessory compartment, a three-way gasoline-distribution valve in the accessory compartment, a gasoline strainer, and the oil pump in order to insure safe operation. The three-way valve and strainer temperatures were obtained because there was some question as to whether vapor lock was present at times in the gasoline line. The thermocouples were made of iron-constantan wire and were led back to the rear cockpit where they were connected through selector switches to a millivoltmeter shown in figure 12. The temperature of the rear cockpit was used for the cold-junction temperature and was measured with a liquid-in-glass thermometer. (See fig. 12.) Oil-in and oil-out temperatures of the engine were obtained with resistance-type bulbs connected to millivoltmeters in the front and rear cockpits.

A schematic layout of the locations of the pressure tubes placed on the airplane is shown in figure 13. Rakes of total- and static-pressure tubes as shown in figure 5 were used to obtain the pressures in the cowling inlet. Two rakes of tubes were used to obtain the pressures in the exit slot of the cowling. (See figs. 7(b) and 8.) Front-baffle pressures and rear-baffle pressures were measured with total pressure tubes located in the manner shown in figures 8 and 9. Although the rear-baffle pressure was obtained with an open-end tube, the velocity head at the point of measurement was negligible and for that reason rear-baffle pressures have been designated in figure 13 with an x, which denotes static pressure. The tubes were led back to the rear cockpit to a junction board shown in figure 12.

In addition to these measurements instruments were provided as shown in figure 12 for obtaining the altitude, engine speed, oil pressure, airspeed, manifold pressure, and fuel-air ratio.

Reduction of Data

Engine-cooling characteristics.- A relation between cylinder temperatures and engine and cooling conditions from which the cooling characteristics of an engine can be determined with a minimum amount of testing has been derived in reference 1. By use of this relation the otherwise necessary but unattainable requirement of exact duplication of all cooling conditions in successive comparative flight tests is avoided and the results can be presented in a general form from which performance can be estimated for conditions not actually flown. This relation is given below.

$$\frac{T_x - T_a}{T_g - T_x} = K \frac{I^{n'}}{(\sigma_2 \Delta H)^m} \qquad (1)$$

where

T_x cylinder-wall temperature, °F

T_a cooling-air temperature, °F

T_g effective gas temperature, °F

K,m,n' constants

I indicated horsepower of engine

ΔH cooling-air pressure drop across heads or barrels of engine, inches of water ($H_2 - H_3$)

H_2	total pressure at front of heads or barrels of engine, inches of water
H_3	total pressure at rear of heads or barrels of engine, inches of water
σ_2	ratio of density of air at front of heads or barrels of engine to standard density (ρ_2/ρ_s)
ρ_2	density of air at front of heads or barrels of engine, slugs per foot^3
ρ_s	standard density, slugs per foot^3 (0.002378)

Relations like equation (1) can be set up for the average of all head temperatures of all cylinders (in which case $T_x = T_h$), the average of all barrel temperatures of all cylinders $(T_x = T_b)$, and the temperature of each individual point of each cylinder. Limiting temperatures were prescribed for the rear-spark-plug gasket and the cylinder-base flange. Therefore, relations between the temperatures at these points and the cooling and engine conditions were required to determine if the cooling was satisfactory for specific conditions. To facilitate the analysis of the data relations like equation (1) were established between the cooling and engine conditions and T_h and T_b. Then curves of T_h plotted against the spark-plug-gasket temperature of each cylinder and T_b plotted against the cylinder-base flange temperature of each cylinder were constructed to establish the relations between the average and the individual temperatures. Previous tests on other engines had shown that definite relations existed between the average and the individual temperatures.

In order to establish the relations between average head and barrel temperatures and the cooling and engine conditions, tests were conducted in which I was the only variable, and the exponent n' was obtained by plotting $(T_h - T_a)/(T_g - T_h)$ and $(T_b - T_a)/(T_g - T_b)$ versus I on logarithmic coordinate paper. Then from tests where both $\sigma_2 \Delta H$ and I were varied the constants K and m were obtained by plotting $(T_g - T_h)I^{n'}/(T_h - T_a)$ and $(T_g - T_b)I^{n'}/(T_b - T_a)$ versus $\sigma_2 \Delta H$ on logarithmic coordinate paper. Straight lines resulted for both of the foregoing plots.

Tests have shown (reference 1) that n'/m is approximately 2 for a number of cylinders and equation (1) can be written in the form

$$\frac{T_x - T_a}{T_g - T_x} = f\left(\frac{I^2}{\sigma_2 \Delta H}\right) \tag{2}$$

and the data for an engine can be plotted on logarithmic coordinates according to this equation and a straight line will result. The symbol f denotes "function of." If the value of n'/m is not close to 2, the data can still be presented in the form of equation (2) by substituting n'/m for the exponent 2 in that equation.

In the present tests the indicated horsepower was obtained from figure 14 knowing the carburetor-air temperature, engine speed, manifold pressure, and back pressure on the engine (obtained from the altimeter reading and standard atmospheric tables, reference 2). The indicated horsepower for a given p_m, p_b, and N at 60° F carburetor-air temperature is obtained from the curves at the top of figure 14 and then the indicated horsepower at the temperature of the test is obtained by means of the correction curve at the bottom of figure 14. The curves of figure 14 were calculated from calibration curves of the manufacturer by a method which is unpublished. The effective gas temperature for an unsupercharged engine varies with fuel-air ratio, spark setting, carburetor-air temperature, compression ratio, and exhaust pressure. The principal variation occurs when fuel-air ratio and carburetor-air temperature are varied. The variation with carburetor-air temperature has been approximated by the following equation derived from tests given in reference 1:

$$T_g = T_{g_o} + 0.8T_a \tag{3}$$

where

T_{g_o} effective gas temperature at 0° F carburetor-air temperature, °F

T_a carburetor-air temperature, °F (equals cooling-air temperature in present tests)

Tests of several cylinders (references 1 and 3) have shown that T_{g_o} at a fuel-air ratio of 0.08 is approximately 536° F for the barrels and 1086° F for the heads of the cylinders. These values were assumed applicable to the Franklin 6-AC-298 engine. In establishing equations like equations (1) and (2) for this engine, T_{g_o} at fuel-air ratios different than 0.08 was obtained from the curves of figure 15, which were obtained from reference 4 because with the carburetor provided with the engine the fuel-air ratio could not be varied over a wide enough range to establish a curve like figure 15.

The above equations are applicable when equilibrium temperatures are obtained. For the case where equilibrium temperatures are not obtained, as in a fast climb, the relation between cylinder temperatures and flight conditions can be obtained by methods given in reference 3. Insufficient data, however, were obtained in the present tests for satisfactory application of these methods and therefore the actual temperatures obtained during the climb test were plotted against the altitude for specific test conditions.

Cowling characteristics.- The object of the following analysis is to obtain cowling characteristics from which it is possible to determine the weight of cooling air flowing and thus the cooling characteristics of the engine, from the pressure available across the cowling for given cowling-exit areas, cowling-flap angles, engine conditions, and flight conditions or to determine the exit area needed for cooling when the engine and flight conditions, flap angle, and weight of cooling air are known.

The relation between the total pressure loss through the cowling and the sum of the losses of the duct elements may be represented by the following equation:

$$\frac{H_o - p_5}{q_{c_o}} = \frac{H_o - H_1}{q_{c_o}} + \frac{H_1 - H_2}{q_{c_o}} + \frac{H_2 - H_3}{q_{c_o}} + \frac{H_3 - H_4}{q_{c_o}}$$

$$+ \frac{H_4 - H_5}{q_{c_o}} + \frac{q_{c_5}}{q_{c_o}} \qquad (4)$$

where

H	total pressure, pounds per square foot
p	static pressure, pounds per square foot
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
q_c	indicated dynamic pressure, pounds per square foot (qF_c)
F_c	compressibility factor $\left(1 + \frac{M^2}{4} + \frac{M^4}{40} + \ldots\right)$
M	Mach number (V/a)
V	velocity of air, feet per second
a	velocity of sound in air $\left(49.2\sqrt{T_a + 460}\right)$, feet per second
T_a	air temperature, $^{\circ}F$

Subscripts:

o	free-stream condition
1	station at duct entrance
2	station at face of engine
3	station at rear of engine
4	station at flap hinge
5	station at flap exit

The station positions are shown in the sketch in figure 16.

The flow losses through any part of the duct system can be approximated by the following equation provided the cowling geometry does not change:

$$\Delta H = C\frac{W^x}{\rho} \qquad (5)$$

where

ρ	average density of the air for the part of the system in question, slugs per foot^3

x	an exponent whose value is near two
C	a constant
W	weight of air passing through the system, pounds per hour

For low speeds, low altitudes, and small heat inputs ρ in equation (5) is approximately equal to ρ_o and q_o can be used in place of q_{c_o} with little error. For such conditions and substituting appropriate values for the constant in equation (5) for each part of the system equation (4) can be approximated by the following equation:

$$\frac{H_o - p_5}{q_o} = \frac{H_o - H_1}{q_o} + \left(C_{1-2} + C_{2-3} + C_{3-4} + C_{4-5} + \frac{C_5}{{A_5}^x}\right)\frac{W^x}{\rho_o q_o} \qquad (6)$$

where

W	weight of air passing through cowling, pounds per hour
C_{1-2}, C_{2-3}, etc.	constants associated with pressure losses from stations 1 to 2, 2 to 3, etc.
C_5	a constant associated with the dynamic pressure in the cowling exit
A_5	flow area at flap exit, square feet
x	a constant

Although the dynamic pressure at the exit varies as $(W/A_5)^2$, the assumption was made that it varied as $(W/A_5)^x$ as x is close to 2 as mentioned previously. Then from equation (6)

$$H_1 - p_5 = \left(C_{1-2} + C_{2-3} + C_{3-4} + C_{4-5} + \frac{C_5}{{A_5}^x}\right)\frac{W^x}{\rho_o} \qquad (7)$$

On the basis of the foregoing assumptions, the pressure loss across the engine is:

$$\Delta H = H_2 - H_3$$

$$= C_{2-3} \frac{W^x}{\rho_o} \qquad (8)$$

Equation (8) is a basic equation giving the relation of the cooling-air-flow rate and density to the loss in total pressure across the engine.

The ratio of the loss in total pressure across the engine to the difference between the total pressure at the cowling inlet and the static pressure at the cowling exit is obtained by dividing equation (8) by equation (7). Or

$$\frac{H_2 - H_3}{H_1 - p_5} = \frac{C_{2-3}}{C_{1-2} + C_{2-3} + C_{3-4} + C_{4-5} + \frac{C_5}{A_5{}^x}}$$

$$= \psi (A_5) \qquad (9)$$

The symbol ψ denotes "function of." The pressure-drop ratio of equation (9) depends only on the exit area. When the variation is known it is possible to predict $(H_2 - H_3)$ for given values of H_1 and p_5.

With the propeller removed and with a good inlet there is usually no loss between stations 0 and 1 due to external expansion of the air or $H_o - H_1$ is about equal to zero. If a propeller having airfoil shank sections is operating in front of the cowling inlet, the inlet pressure H_1 may be greater or less than H_o by an amount depending on the thrust loading of the propeller, the angle of attack α of the airplane, and the location and shape of the inlet. The relation between the free-stream and inlet-total pressures for a given inlet may be expressed by the following equation:

$$\frac{H_o - H_1}{q_o} = \phi (T_c, \alpha) \qquad (10)$$

where

T_c	thrust coefficient $(T/\rho_o V_o^2 D^2)$
T	propeller thrust, pounds
η	propeller efficiency (TV_o/P)
P	brake power of engine, foot-pounds per second
V_o	airplane speed, feet per second
D	propeller diameter, feet
ρ_o	density of air in free stream, slugs per foot^3
α	angle of attack of airplane
ϕ	denotes "function of"

For a limited range of flight conditions and with a fixed pitch propeller, the propeller-power coefficient, P_c $(= P/\rho_o V_o^3 D^2)$ is approximately proportional to T_c. For these conditions and because of the fact that for this type of cowling $\frac{H_o - H_1}{q_o}$ is practically insensitive to α, the loss or gain of total pressure from the free stream to the inlet may be approximately determined by means of the following equation:

$$\frac{H_o - H_1}{q_o} = \phi' \, (P_c) \qquad (11)$$

The symbol ϕ' denotes function of P_c and is different from the ϕ used in equation (10). Equation (11) may be used to predict the cowling-inlet pressure for conditions of power, airspeed, and altitude other than those for which the tests were made.

It has been shown (reference 5 and other references not mentioned herein) that, for a given angle of attack, $\frac{H_o - p_5}{q_o}$ depends mainly on the cowl-flap setting and the local slipstream velocity. The effects of the slipstream have been ignored since the tests were not sufficiently complete to isolate them and the following expression has been used to correlate the outlet pressures:

$$\frac{H_o - p_5}{q_o} = f\ (\text{flap angle}) \qquad (12)$$

Thus, from a determination of the variation of $(H_o - p_5)/q_o$ with flap angle for each angle of attack, the pressure p_5 can be obtained for any flight condition.

Summing up: equation (8) gives the cooling-air flow in terms of air density and pressure drop across the engine; equation (9) gives the ratio of the pressure drop across the engine to the difference between the cowling-inlet total pressure and exit-static pressure as a function of exit area; equation (11) gives the relation of inlet-total pressure to the propeller-power coefficient and free-stream conditions; and equation (12) gives the exit-static pressure as a function of exit-flap angle and free-stream conditions.

On the basis of the foregoing analysis, the aerodynamic results of the installation were reduced to plots of the following form:

$$\sigma_2\ (H_2 - H_3) \text{ versus } W \text{ (logarithmically)}$$

$$\frac{H_2 - H_3}{H_1 - p_5} \text{ versus } A_5$$

$$\frac{H_o - H_1}{q_o} \text{ versus } P_c$$

$$\frac{H_o - p_5}{q_o} \text{ versus flap angle}$$

In determining the foregoing relations from the test data the weight of air W was determined from the tests with configuration A using the data obtained at the cowling exit with the pressure rakes and the thermocouples behind the engine. The curve of $\sigma_2\ (H_2 - H_3)$

versus W established was used to determine the weights of air for all other exit areas from the pressure-drop data across the engine. Such a procedure was used because the rakes spanned only part of the cowling exit when the large exit areas were tested. No flap was used with the 41- and 75-square-inch-cowling exit areas and the pressures recorded in the exit were the pressures p_5 according to the symbolization of this report. In the tests with the 135-square-inch exit the rakes were placed approximately at station 4 and the pressures p_5 were calculated from the measured pressures assuming H_5 equals H_4.

The density ρ_2 instead of ρ_0 was used to establish the relation between W and $(H_2 - H_3)$ to correct for small changes in density that occurred between station 0 and 2. Use of ρ_2 instead of ρ_0 for determining this relation is more rigorous and involved no complication in the relation. Such usage, however, in the other aerodynamic relations would have complicated them unduly.

The brake power used in determining P_c was calculated by subtracting the friction horsepower from the indicated horsepower. The method of obtaining the indicated horsepower has been given in the cooling analysis. The friction horsepower was calculated from the equation

$$\text{fhp} = \frac{\text{fmep} \times d \times N}{33{,}000 \times 2 \times 12} \qquad (13)$$

The fmep was obtained from the curves of figure 17 for the manifold pressure, back pressure, and engine speed of each test. The method of obtaining fmep from the curves is self-evident on the figure.

Test Program

Tests of the type shown in the following table were made to determine the cowling and cooling characteristics. The fuel-air ratio was maintained as close to 0.085 as possible in all of the tests except test 8. The fuel-air ratio was varied in this test in order to attempt to obtain its effect on the variation of effective-gas temperature. As previously mentioned, however, the carburetor used would not permit a large enough range of fuel-air ratio to establish the relation. Several runs of some types of tests were made for check purposes or to determine the effect of baffle and cowling alterations. A minimum of 5 minutes was allowed for the temperatures to stabilize.

TEST PROGRAM

Test no.	Type of test	Purpose of test			
1	Ground test. After preliminary checking of the engine on the ground, the maximum engine speed at which the engine cooled continuously was determined. The temperatures were then checked at one-half the foregoing speed and at an intermediate speed.	To determine ground cooling characteristics and relation between cooling-air flow and pressure drop across engine	To determine relation between total pressure at cowling entrance and power coefficient.	To determine relation between cooling characteristics and cooling-air flow.	To determine relations between static pressure at cowling exit, total pressure at cowling entrance, pressure drop across engine, flap angle, and cowling-exit area.
2	Altitude, 1000 feet; indicated airspeed, 80 miles per hour; throttle wide open; wing flaps adjusted to obtain level flight. Data recorded for stabilized conditions.				
3	Altitude, 10,000 feet; indicated airspeed, maximum; throttle wide open; wing flaps up. Data recorded for stabilized conditions.				
4	Altitude, 5000 feet; indicated airspeed, maximum and that for climb; throttle setting reduced for level flight at the climb speed; wing flaps up. Data recorded for stabilized conditions.				

TEST PROGRAM - Continued

Test no.	Type of test	Purpose of test			
5	Altitude, 1000 feet; indicated airspeed varied by varying throttle setting level flight; wing flaps up. Data recorded for stabilized conditions.	To determine relation between cooling air flow and pressure drop across engine.	To determine relation between total pressure at cowling entrance and power coefficient.	To determine relation between cooling characteristics and cooling air flow.	To determine relations between static pressure at cowling exit, total pressure at cowling entrance, pressure drop across engine, flap angle, and cowling exit area.
6	Altitude, 1000 feet. A reference baffle pressure drop was read with a 90-mile-per-hour indicated airspeed. Reference air pressures, all temperatures, and engine data were recorded after a stabilization period. The wing flaps were then lowered to increase the drag, the airspeed and engine speed readjusted to maintain level flight, and the reference baffle-pressure drop and the reading taken again. The procedure was repeated for five flap settings in order to obtain as great a variation of engine power as possible.	To determine variation of cooling characteristics with horsepower.			

TEST PROGRAM - Concluded

Test no.	Type of test	Purpose of test			
7	Wide-open throttle climb. Airplane leveled off at 1000 feet and temperatures stabilized with wide-open throttle. Then climbed at constant indicated airspeed to the service ceiling. In the rear cockpit continuous readings of only the rear spark-plug temperatures, one front and one rear-baffle pressure were taken due to the time element. Pressure represented average of the other pressures at coresponding positions.	To determine cooling characteristics in climb.			To determine relations between static pressure at cowling exit, total pressure at cowling entrance, pressure drop across engine; flap angle and cowling exit area
8	Altitude, 1000 feet, indicated airspeed, constant; engine speed approximately cruising speed; fuel-air ratio varied in steps over as large a range as possible. Change in engine power with change in fuel-air ratio compensated by small changes in throttle setting.	To determine change in cooling with change of fuel-air ratio.			

RESULTS

Engine cooling.- The cooling-correlation results of the level flight and ground tests are shown in figure 18. Practically all of the cooling data for these tests are shown in this figure. A few runs made during the latter part of the investigation were not included because the engine was not operating satisfactorily. A single curve resulted when values of $(T_b - T_a)/(T_g - T_b)$ were plotted against values of $I^2/\sigma_2 \Delta H$ and another similar curve represented all of the head data. (See fig. 18.) These curves were straight lines on a logarithmic plot with a slope of 0.5. The exponent 2 in the abscissa was obtained from construction plots which have been previously described. An average of all the head and barrel pressures was used for ΔH in figure 18 because the pressure distribution was very uniform in front of and behind the engine. The term $\sigma_2 \Delta H$ was adequate for correlating the cooling data of the present tests but for high-altitude airplanes with large heat output engines it is necessary to correct for change in σ across the engine before adequate correlation can be obtained.

The relation of the spark-plug temperatures of each cylinder to T_h and of the flange temperatures of each cylinder to T_b are shown in figures 19 and 20, respectively. Although some of the data do not agree very well with the curves drawn, no definite trend in the data points could be detected, there just being a random scatter about the curves. It is thought that figures 19 and 20 are fairly representative of the variation of individual temperatures with average temperatures with the exception of two or three thermocouples.

The result of the ground test with configuration B at a speed at which the engine could be operated continuously is shown in table II. The results show that at the air temperature of the test, 51° F, all temperatures were satisfactory but cylinder 4 spark-plug temperature was very near the limit, 525° F, and other temperatures would exceed or be near the limit at the CAA sea-level air temperature of 110° F (reference 6). The allowable limit for the cylinder-base flange temperature was 330° F. The temperatures attained in high-speed level flight at about 1000 feet altitude with the same installation configuration are also shown in table II. It is quite evident that the engine would not cool satisfactorily at CAA standard-air temperatures; the head temperatures of at least four cylinders would exceed the limit and possibly the flange temperatures of two cylinders.

The spark-plug temperatures attained in climb from sea level to 10,000 feet with configuration B are shown in figure 21 along with other pertinent data. No points are shown on the curves as they were obtained from faired curves of the data plotted against time. The hottest temperature occurred at the low altitudes and probably a couple of cylinders will be over the temperature limit at these altitudes if the air temperature is CAA standard. Temperatures calculated from the cooling and engine conditions using the curves of figures 15, 18, 19, and 20 showed fair agreement with the observed temperatures at the low altitudes. At high altitudes the agreement was fair except for cylinders 1 and 6. Inasmuch as the slopes of the temperature curves with altitude variation of figure 21 for cylinders 1 and 6 are much different than the slopes of the curves for the other cylinders, it is thought that probably the thermocouple readings were in error for these two cylinders at the high altitudes.

Because the temperatures were hotter at low altitudes than at high altitudes and because the calculated temperatures in climb were in fair agreement with the observed temperatures which indicated that the latter were near the equilibrium values, all tests to determine the effects of changes in baffles and cowling were conducted at about 1000 feet altitude and in level flight. No original data are given here for the effects of these changes because the conditions during the tests varied and the observed temperatures cannot be compared. The comparisons of these temperatures calculated for specific conditions are given later.

Aerodynamics of cowling installation.- The pressure drop across the engine for various air quantities flowing, calculated from data obtained with the 41-square-inch exit, is shown in figure 22. The points fit the curve very well, thus giving confidence in the pressure measurements at the exit from which the weight of air was calculated.

The relation of $(H_2 - H_3)/(H_1 - p_5)$ to cowling-exit area is given in figure 23. The points are arithmetical averages of all tests made with each area because the variation of $(H_2 - H_3)/(H_1 - p_5)$ at each area with test conditions was small. Figure 23 shows the gain in what might be called useful pressure drop $(H_2 - H_3)$ as the area increases. At 41-square-inch area, only about 0.5 of the pressure difference from front to rear of the cowling is available for cooling but with 135-square-inch area about 0.8 of the total difference is available. This increase in pressure difference available for cooling results in a direct increase in cooling-air quantity flowing through the cowling and thus an improvement in cooling.

The relation between H_1, the propeller-power coefficient, P_c, and free-stream conditions can be obtained from figure 24. Points for all of the tests conducted are given in the figure. At the highest value of P_c a value of $(H_o - H_1)/q_o$ of almost -0.8 was obtained showing that the free-stream pressure was boosted almost $0.8q_o$ at the cowling inlet. This value is much higher than pressures that are usually obtained in inlets and indicates that the location and design of the inlet was more than satisfactory.

The over-all loss through the cowling $(H_o - p_5)/q_o$ is plotted in figure 25 against flap angle. The values of $(H_o - p_5)/q_o$ varied little at any one-flap setting so that all the values for each exit area were averaged and these averages plotted. As no flap was used with the 41- and 75-square-inch exits, it would be expected that p_5 would about equal p_o. That such was the case is shown in figure 25 because $(H_o - p_5)/q_o$ for these two areas was about 1.0. With the 30° flap a boost of $0.3q_o$ in $(H_o - p_5)$ above that at 0° flap angle was obtained. No tests were made at other flap angles so an assumed line has been drawn through the data based on other test results.

The weights of air flowing through the cowling for all the test runs are plotted in figure 26 against the pressure loss $\sigma_o(H_1 - H_2)$. The weights of air were obtained from figure 22 knowing the pressure drop across the engine. Some scatter of the data about a line drawn with the slope that is usually obtained is apparent. The pressure differences were so low, however, as to be within the accuracy of the pressure measuring equipment. The loss from the cowling inlet to the face of the engine was roughly 0.2 of the free-stream dynamic pressure. No curve on this basis is given for the loss $(H_3 - H_4)$ as this loss was negligible.

PREDICTED COOLING PERFORMANCE

Effect of Cowling and Baffle Alterations

Several cowling and baffle alterations were made in order to improve the engine cooling obtained with configuration B. These alterations are detailed in table I, configurations C to H. In determining the effect of the alterations the engine temperatures for configurations B to H were calculated for CAA air-temperature conditions. The test values of indicated horsepower, brake horsepower, density of the free air, T_g, σ_2, and q_o were all corrected to CAA air temperature. In calculating q_o the assumption was made that the drag coefficient and propulsive efficiency were the same for the standard conditions as for the test conditions. For ground runs it was assumed that ΔH of the test remained unchanged when temperature varied. The temperatures were then calculated using these corrected data and figures 18, 19, 20, 23, and 24.

The results of the calculations for the various configurations are shown in table III. With the 41-square-inch exit area, configuration B, most of the spark-plug temperatures and some of the flange temperatures exceeded the limits in the ground run (test 1, run 6). In the full-throttle level-flight test (test 5, run 2) two spark-plug temperatures exceeded the limit. The hottest cylinders were numbers 3 and 4. (See fig. 11.) A few tests were conducted on the ground to determine whether the large temperature change from cylinder to cylinder was caused by poor fuel distribution by determining the fuel-air ratio of each cylinder from exhaust-gas samples. The fuel-air ratios of the cylinders were found to be about the same.

With the 75-square-inch-cowling exit area, configuration C, the temperature decreased about 40° F on the ground and about 30° F in level flight at 1000 feet altitude as compared to the results with configuration B. No temperature was over its limiting value in the level-flight test, although cylinder 4 spark-plug temperature was close to the limit (515° F), but in the ground tests cylinders 2, 3, and 4 spark-plug temperature exceeded the limiting value.

Tests were then made with spark-plug baffles, a blast tube, and baffle ducts but the test results were inconclusive and in general little or no decrease in temperatures was obtained.

Although the test results with the spark-plug baffles had proved inconclusive, they were installed on cylinders numbers 3 and 4 when the exit area was increased to 135 square inches and a fixed flap was used (configuration H). The spark-plug temperatures of cylinders 3 and 4 at 1000 feet altitude and in level flight with this configuration were decreased about 45° F and the other cylinder spark-plug temperatures about 35° F as compared to the results with configuration C. Of course, no flap would be used in high-speed level flight. It was necessary to operate the airplane in such a manner in order to obtain data upon which the design of the exit, to be given in the next section, could be based. The engine began to operate unsatisfactorily at this point and the tests were discontinued. No climb or ground tests were made with configuration H. The area of the cowling exit required for adequate cooling was calculated instead for both level-flight and climb conditions from the data that had been obtained up to the time of discontinuing the tests.

Cowling-Exit Area for Adequate Cooling

The cowling-exit area required for adequate cooling was calculated for engine and cooling conditions for the climb test at 1000 feet altitude for a high-speed level-flight test at 1000 feet altitude (test 5, run 13) and for a level-flight high-speed test at 10,000 feet altitude (test 3, run 1) corrected to CAA air temperature as explained in the previous section of the report. The areas were calculated on the basis of no spark-plug temperature exceeding 525° F using the corrected conditions and figures 15, 18, 19, 23, 24 and 25. For high-speed level flight a flap angle of 0° was used and for climb a 30° angle was used. The results of the calculations are given in table IV.

The results in the table show that adequate cooling will result with 63-square-inch exit area in high-speed level flight at 1000 feet altitude. This conclusion is substantiated in table II where for approximately the same conditions and 75-square-inch area the temperature of cylinder 4 was 515° F. At 10,000 feet, due to the rapid fall off in engine power, only 32-square-inch exit area is required. For climb at 1000 feet, a value of $(H_2 - H_3)/(H_1 - p_5)$ of 0.9 was obtained for the conditions set up. This was beyond the range of the tests and for this reason the exit area required has been denoted in table IV as being somewhat greater than 135 square inches. There is some doubt that the value of 0.9 could be obtained because the curve in figure 23 is flattening rapidly. It is thought, however, that the engine will cool in climb with the flap provided and 135-square-inch exit area because the temperatures fall off rapidly as altitude increases (fig. 21) and in addition equilibrium temperatures are not usually attained in climb. If the same decrease in temperatures is obtained on the ground as in flight when the exit area is changed from 75 to 135 square inches and a flap is used, the ground cooling will be adequate. As mentioned previously, no tests were made to check these points because of unsatisfactory operation of the engine.

To sum up, the aerodynamic results of the cowling design used were good, especially the high-cowling inlet pressures obtained. Any improvement in cooling will have to be obtained by improved fin designs on the engine cylinders and/or use of a cooling blower.

CONCLUDING REMARKS

With the cowling inlet relocated as in the new design behind the active part of the propeller the highest total pressure in the inlet was about $0.8q_0$ greater than that in the free stream. This pressure is much higher than those usually obtained in cowling inlets. With a cowl-flap angle of 0° the pressure at the cowling exit p_5 was about equal to free-stream static pressure p_0. The greatest pressure difference $(H_1 - p_5)$

from cowling inlet to cowling exit with this flap angle was thus about $1.8q_o$. With a flap angle of 30°, the depression at the cowling exit was $-0.3q_o$ giving a maximum value of $H_1 - p_5$ of $2.1q_o$ at high values of propeller-power coefficient. These values of $H_1 - p_5$ decreased to 1.5 and 1.8, respectively, at low values of the propeller-power coefficient.

The loss in total pressure from the cowling inlet to the upstream face of the engine with the altered cowling inlet was roughly 0.2 of the free-stream dynamic pressure. The loss from the downstream side of the engine to the cowling exit was negligible. With the altered cowling adequate cooling can be obtained in high-speed level flight with a cowling-exit area of 63 square inches at an altitude of 1000 feet and 32 square inches at 10,000 feet. It is probable that cooling in climb and on the ground will be satisfactory with 135-square-inch-cowling exit area and a flap angle of 30°. Further improvement in cooling of the subject power-plant installation must be obtained by some means other than the cowling design.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics
Langley Field, Va., May 13, 1944

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TABLE I
ORIGINAL AND ALTERED POWER-PLANT INSTALLATION FEATURES

Configuration	Cowling Installation					Cylinder Baffle Installation				Carburetor duct installation	Oil-cooler installation	Illustration
	Inlet	Outlet	Exit area (sq. in.)	Flap	Cooling air flow	Cylinder baffles	Spark-plug baffles	Blast tube	Baffle ducts			Figure nos.
A (as received)	Two small openings in nose of cowling above engine and behind the blade shanks	Side and bottom openings below the engine at rear of cowling	Unknown	None	From top to bottom of engine	None	None	None	None	Front underslung external scoop. Special carburetor air heating ducts.	Two coolers under engine projecting partially through openings in bottom of cowling	1 & 2
B	One large opening in nose of cowling below engine and behind airfoil section of propeller	Opening at top rear of cowling skirt	41	None	From bottom to top of engine	Sheet-metal baffles fitted tight against fins around rear half of all cylinder barrels and heads	None	None	None	Hot and cold air duct arrangement inside cowling below engine	One cooler slung below fuselage just aft of cowling skirt; temporary arrangement	3,4,5,6,8,9
C			75	None			None	None	None			3,4,5,6,8,9
D			75	None			On cyl. #4	None	None			3,4,5,6,8,9,10
E			75	None			On cyls. #4 & 6	None	None			3,4,5,6,8,9,10
F			75	None			On cyls. #4 & 6	On cyl. #4	None			3,4,5,6,8,9,10
G			75	None			None	None	On cyls. #4 & 6			3,4,5,6,8,9,10
H			135	Fixed flap 30° angle			On cyls. #3 & 4	None	None			3,4,5,6,7,8,9,10

TABLE II

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OBSERVED TEMPERATURES WITH CONFIGURATION B

Type of test	ground		level flight	
Test no.	1		5	
Run no.	6		2	
Cowling exit area, sq. in.	41		41	
Indicated horsepower	84.9		148.2	
Brake horsepower	73.2		121.9	
Engine speed, r.p.m.	1810		2800	
Fuel-air ratio	0.085		0.087	
Cooling-air temperature, °F	51		60	
Carburetor-air temperature, °F	51		60	
Airspeed, mph	0		134	
$\sigma_2 \Delta H$, in. of water	1.25		6.07	
Temperature, °F	Rear spark plug	Flange	Rear spark plug	Flange
Cylinder 1	402	219	404	236
2	465	256	496	265
3	495	233	518	244
4	522	274	524	270
5	429	209	463	238
6	483	279	478	286

TABLE III.- EFFECT OF COWLING AND BAFFLE ALTERATIONS ON COOLING OF FRANKLIN 6-AC-298 ENGINE (CAA AIR TEMPERATURE BASIS).

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Configuration	B	C	D	B	C	E	F	H
Test	1	1	1	5	5	5	5	5
Run number	6	8	9	2	5	7	8	13
Cowling exit slot area, sq. in.	41	75	75	41	75	75	75	135
Cylinder baffles								
Spark-plug baffles	-	-	Cyl. 4	-	-	Cyl. $<{4 \atop 6}$	Cyl. $<{4 \atop 6}$	Cyl. $<{3 \atop 4}$
Blast tube	-	-	-	-	-	-	Cyl. 4	-
Cowl flap	-	-	-	-	-	-	-	-
Indicated horsepower	80.4	82.1	82.0	141.6	141.0	138.1	137.4	138.9
Brake horsepower	68.7	70.5	70.3	115.0	115.1	112.8	111.8	113.5
Engine speed	1810	1820	1820	2800	2770	2740	2730	2730
Fuel-air ratio	0.085	0.086	0.084	0.087	0.086	0.088	0.088	0.087
Altitude, feet	0	0	0	990	999	1000	980	1000
True airspeed, mph	0	0	0	134	132	130	129	129
Cooling-air temperature, °F (CAA)	110	110	110	110	110	110	110	110
$\sigma_2\Delta H$, in. of water	1.12	1.47	1.74	5.44	6.94	7.05	6.70	9.34
Rear spark-plug temp., °F *								
Cylinder 1	486	477	446	433	410	399	403	376
2	591	549	535	514	485	466	473	436
3	619	579	560	541	509	493	499	461
4	620	579	564	546	515	499	505	472
5	525	497	487	474	451	440	444	417
6	552	522	511	498	477	465	469	444
Flange temperature, °F **								
Cylinder 1	306	290	272	278	267	251	261	244
2	324	309	291	296	286	270	280	263
3	308	292	275	280	271	255	264	247
4	332	316	298	303	294	278	287	271
5	303	287	270	275	266	260	259	243
6	338	322	306	310	300	284	294	276

* Temperature limit 525 °F

** " " 330 °F

TABLE IV

COWLING EXIT AREA NEEDED FOR ADEQUATE COOLING

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Type of flight	High-speed level flight	High-speed level flight	Full throttle climb
Altitude, feet	1,000	10,000	1,000
True airspeed, mph	128	119	86
Indicated horsepower	139	95.5	133
Cooling-air temperature, °F (CAA)	110	80	110
Fuel-air ratio	0.087	0.088	0.088
Cylinder 4 spark-plug temp., °F	525	525	525
ΔH, in. of water	6.9	3.2	6.7
Area of cowling exit required, sq.in.	63	32	135^{+}

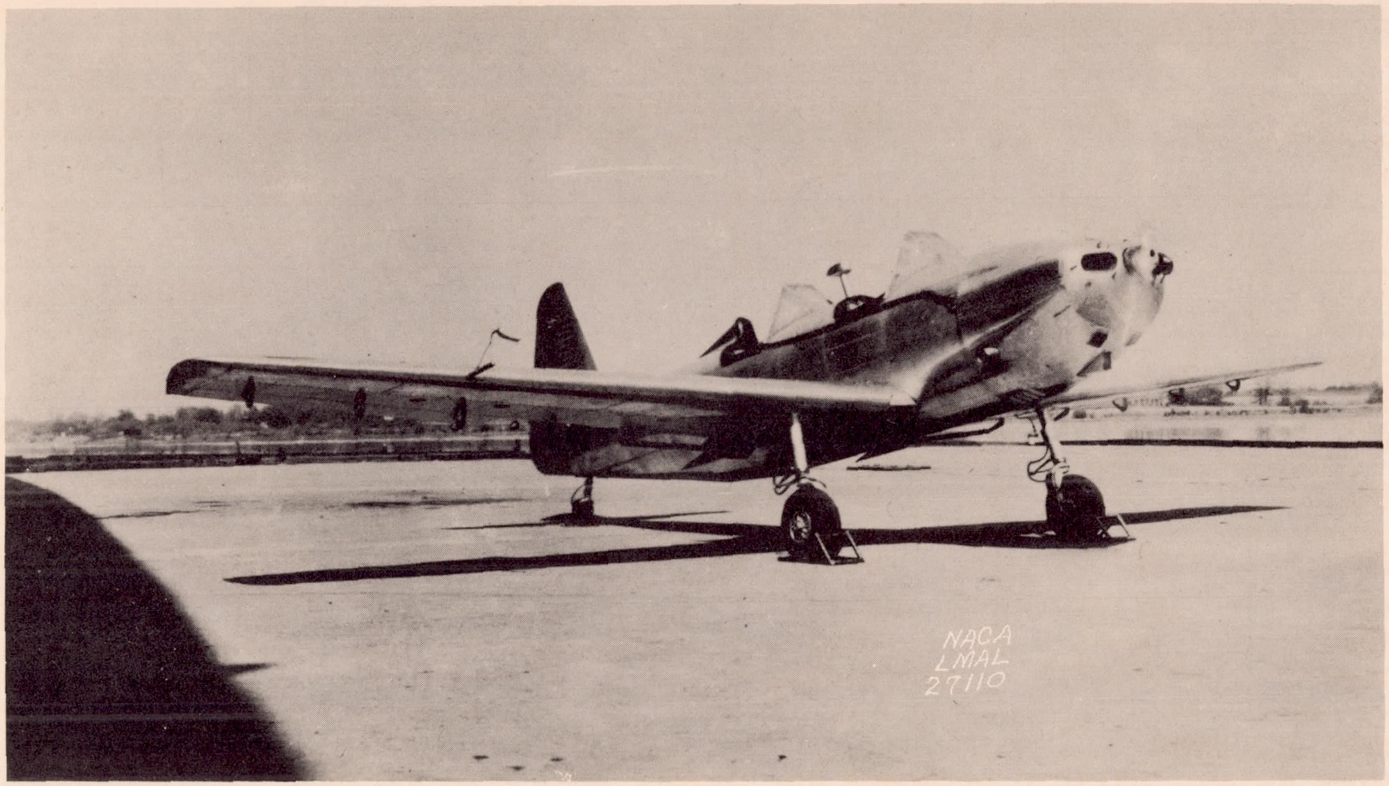

Figure 1.- Fleetwings model 33 trainer with original cowling installation.

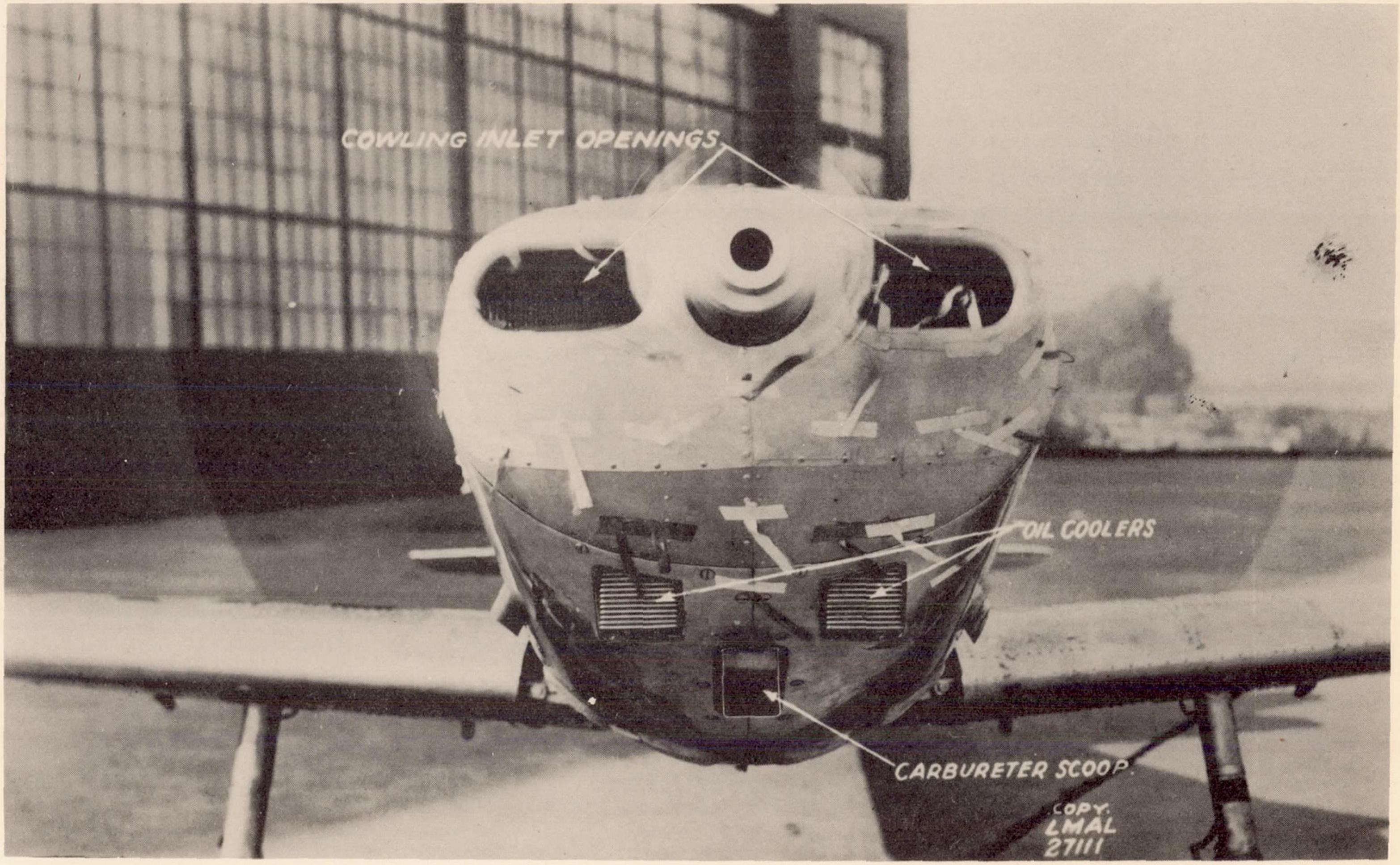

Figure 2.- Front view of original cowling installation on Fleetwings model 33 airplane.

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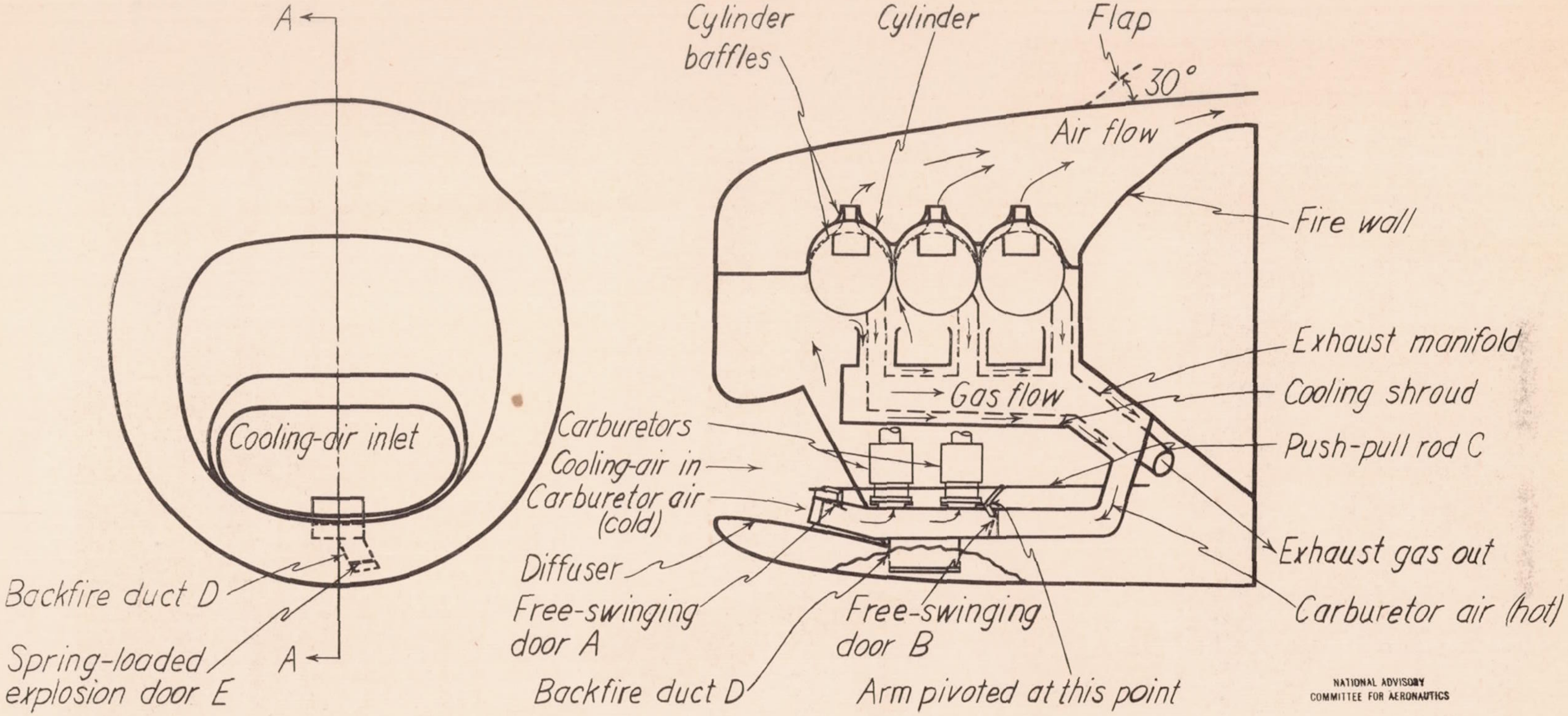

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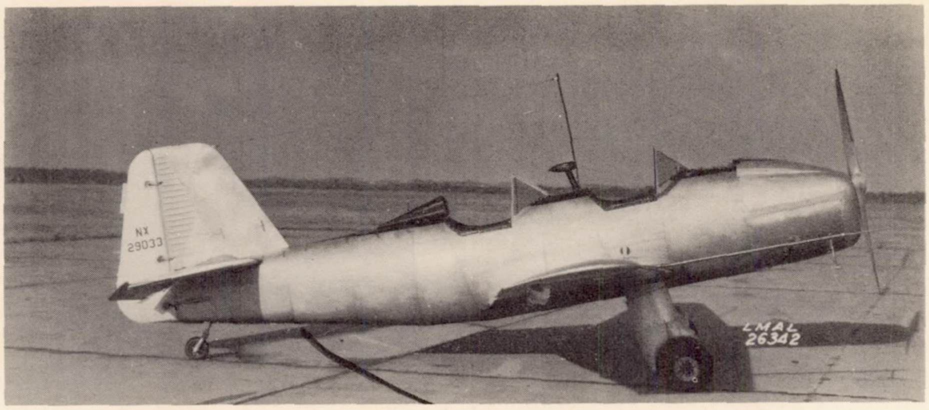
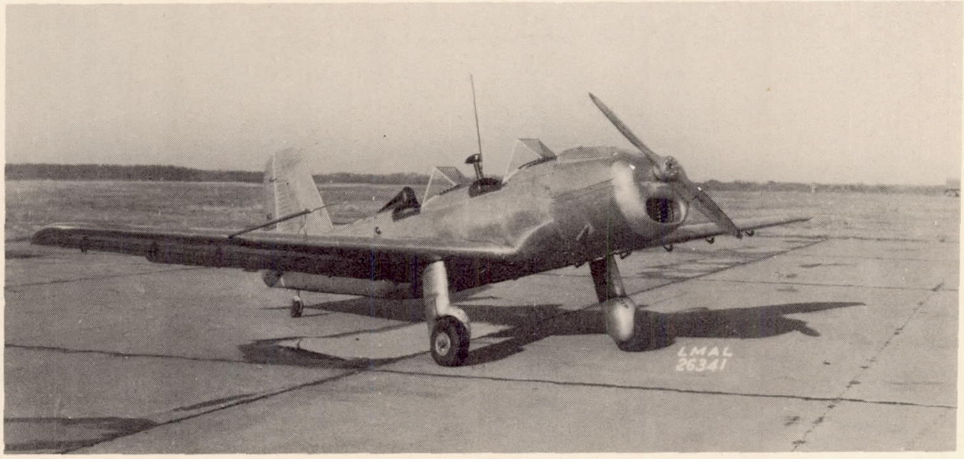
Front of cowling

Section AA

Figure 3.- Diagrammatic sketch of powerplant and cowling installation.



(a) Side view.



(b) Three-quarter view.

(c) Front view.

Figure 4.- Fleetwings model 33 trainer with first cowling alteration (configuration B).

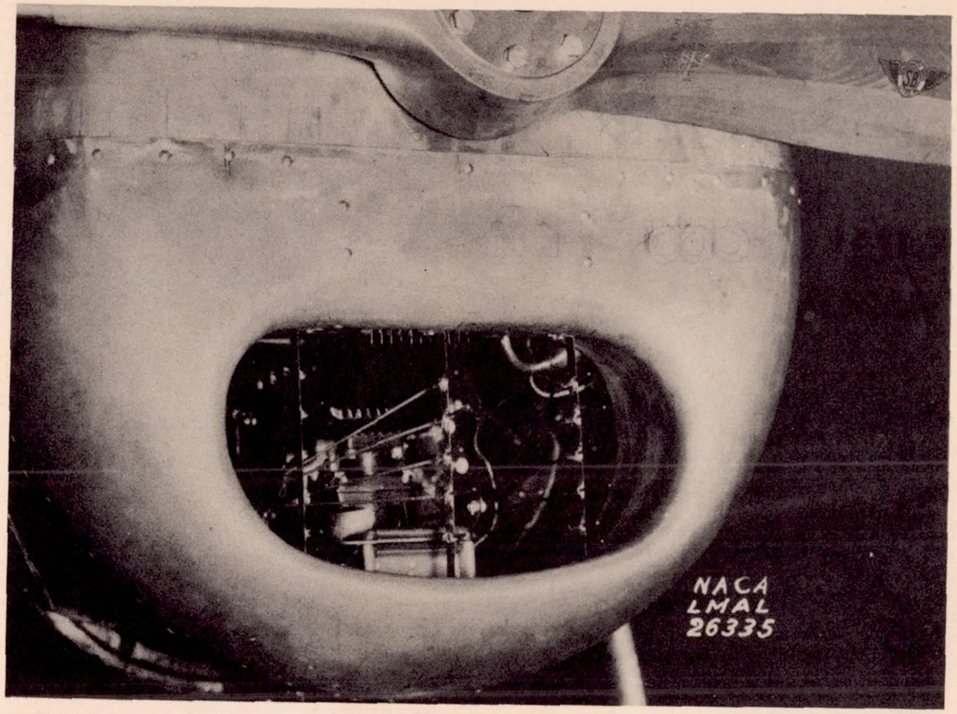


Figure 5.- Front view of inlet opening of altered cowling.

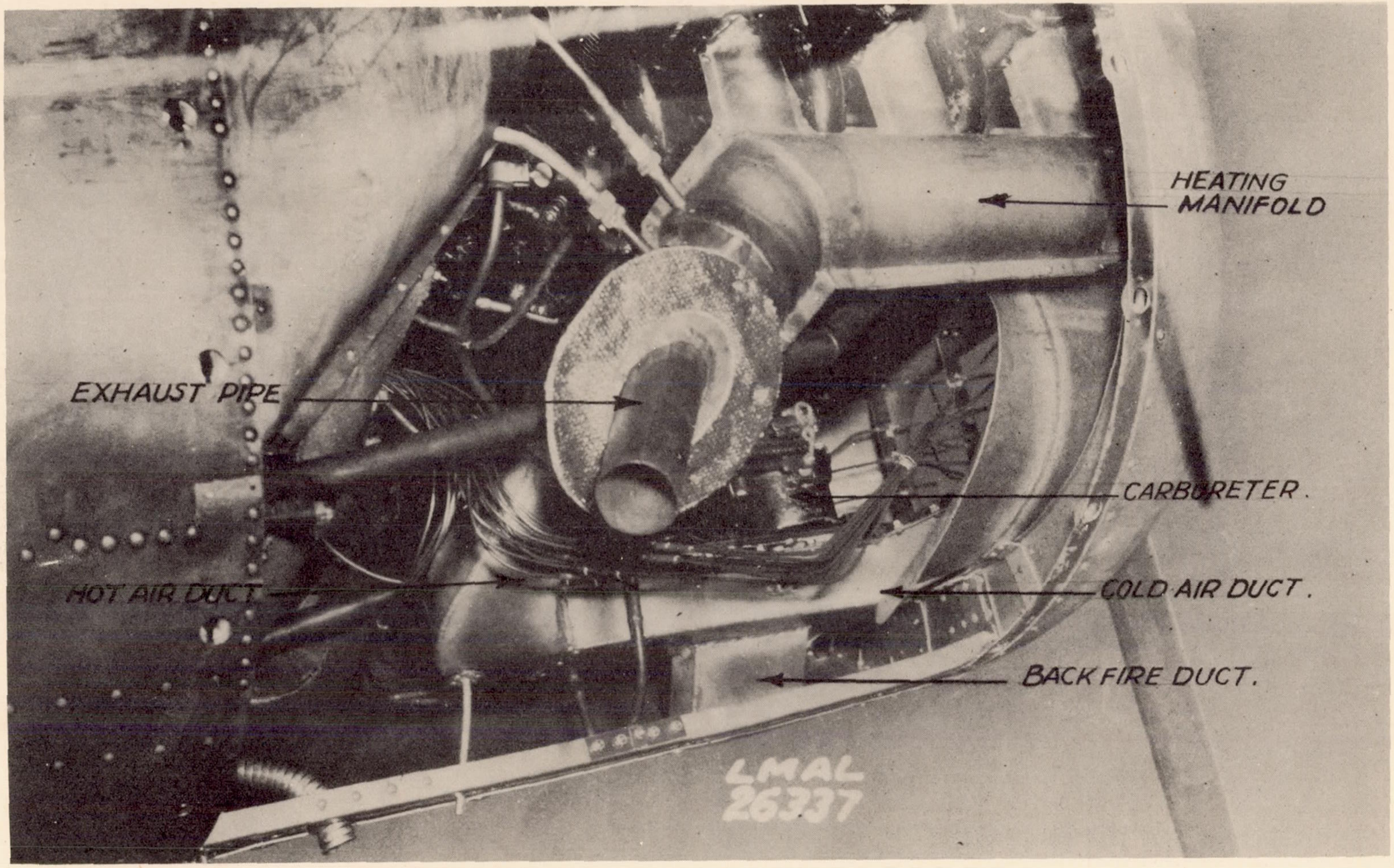
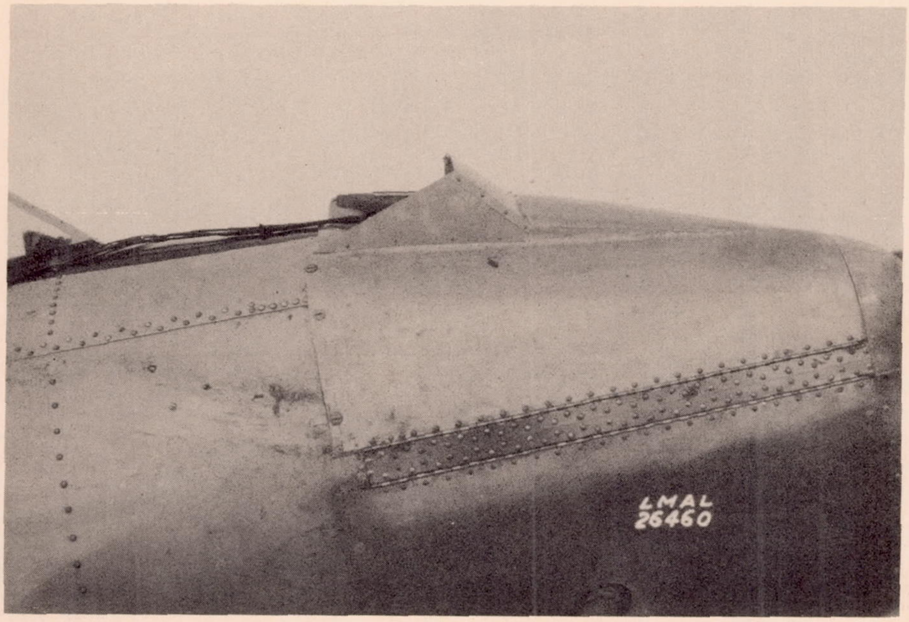
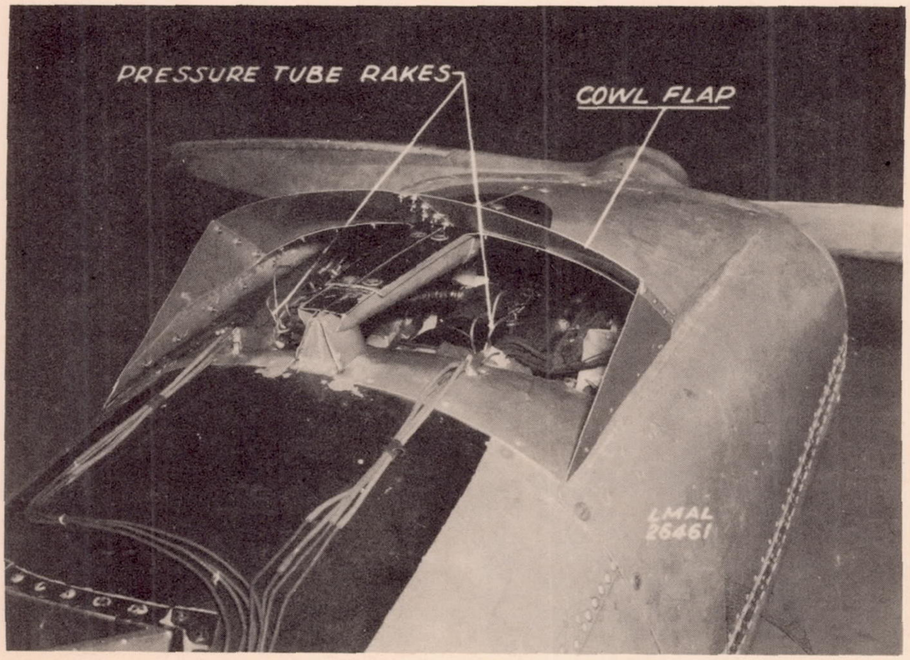


Figure 6.- Modified carburetor duct system in Fleetwings model 33 airplane.



(a) Side view.



(b) Rear view.

Figure 7.- Views of cowling exit with flap.

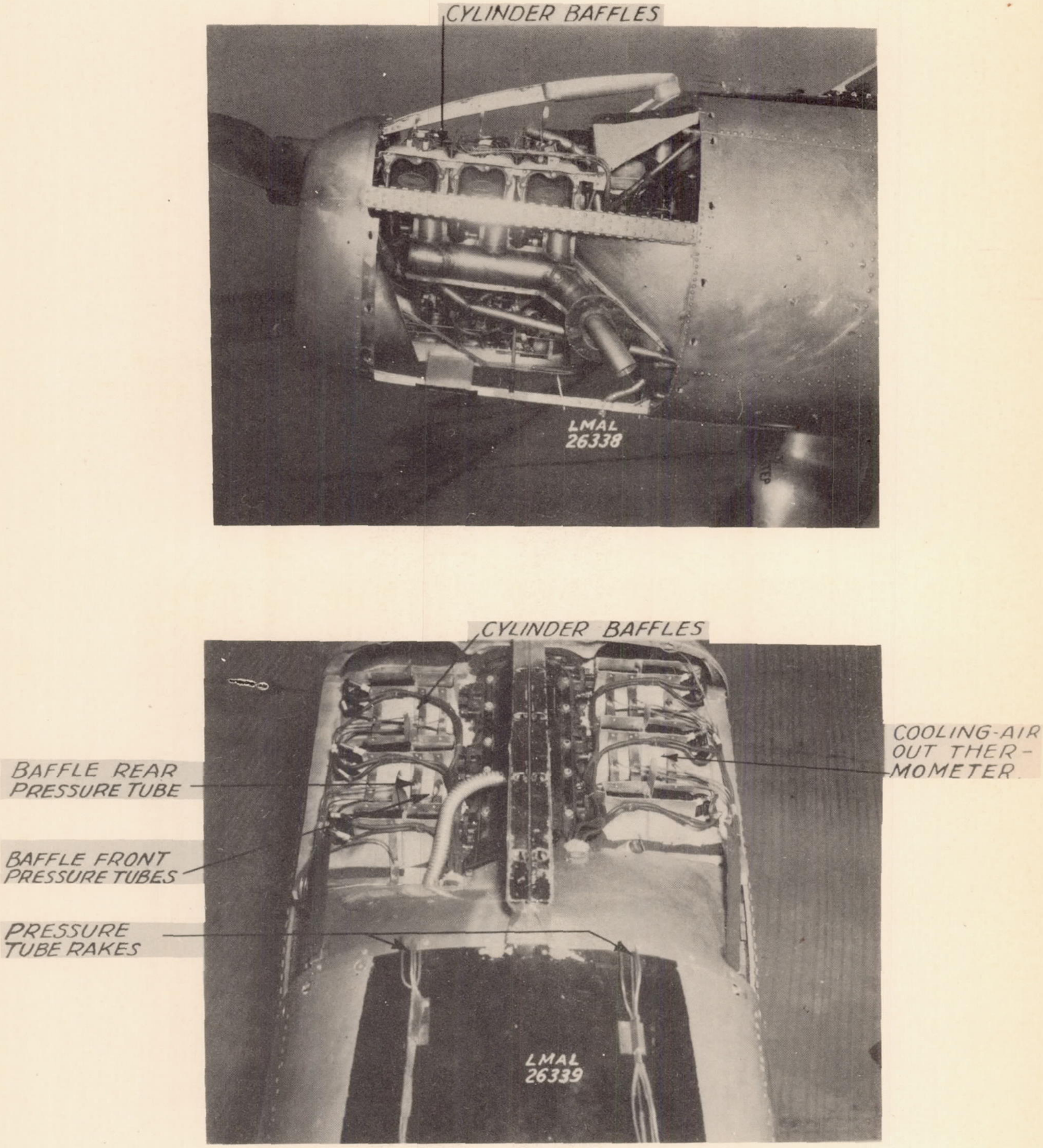


Figure 8.- Two views of engine showing baffle installation.

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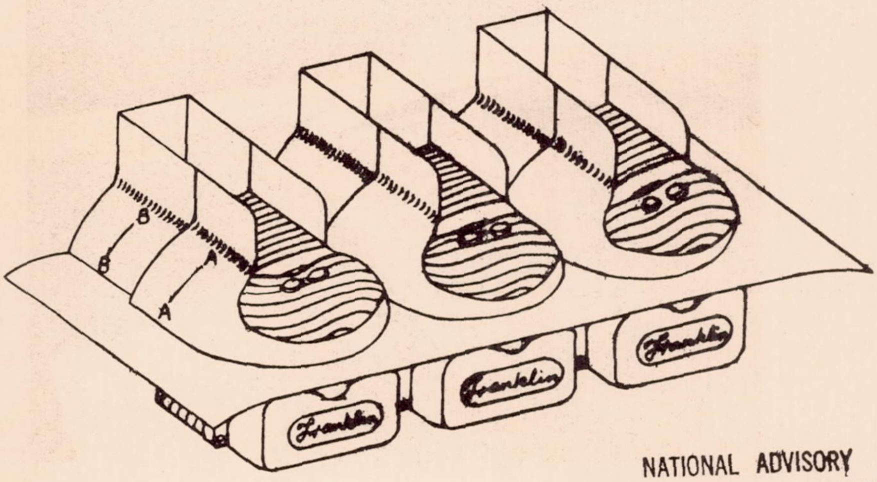
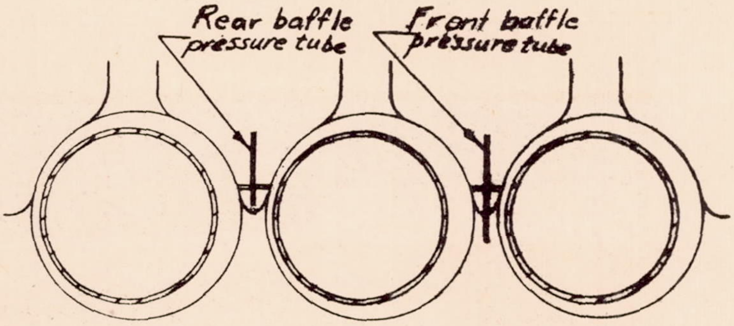
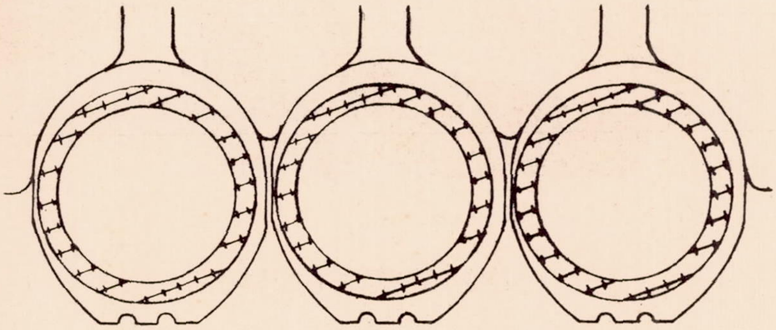


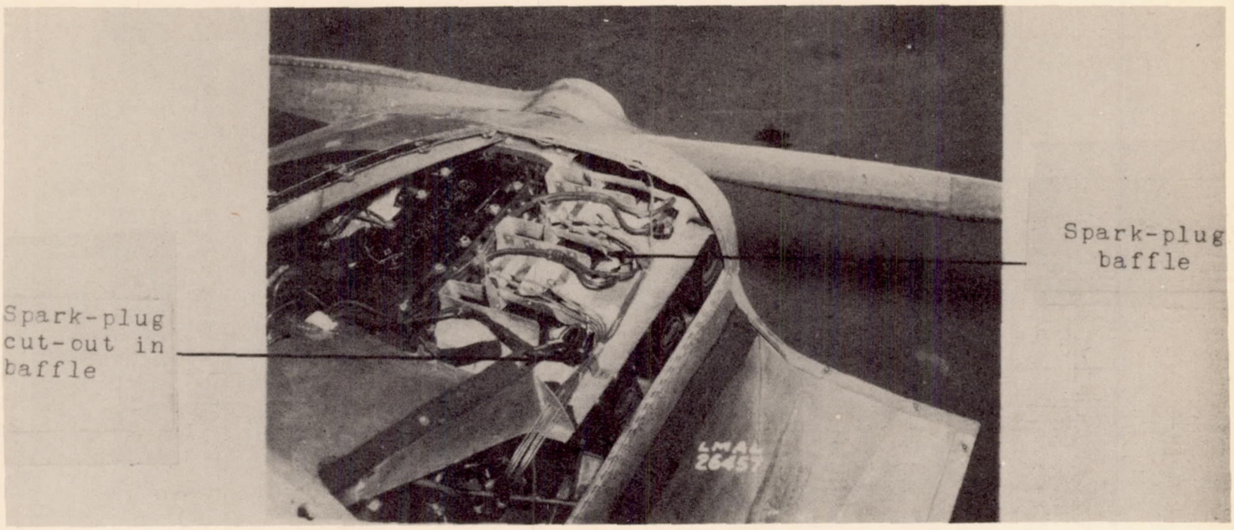


Section through plane of B—B

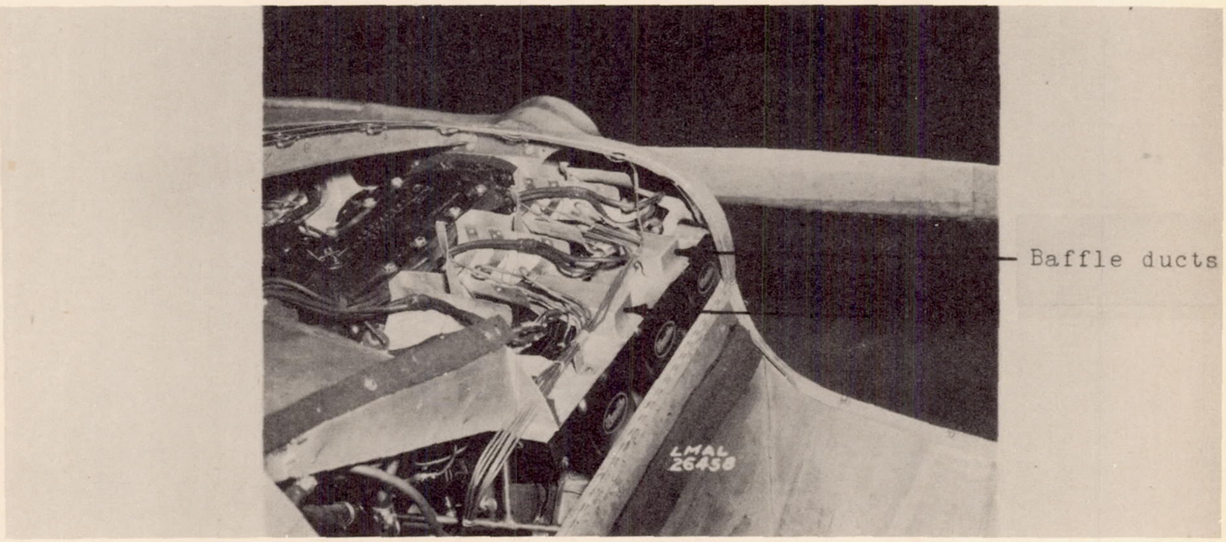


Section through plane of A—A

Figure 9.- Sketch showing baffles for Franklin 6-AC-298 engine in Fleetwings model 33 airplane.



(a) Spark-plug baffle.



(b) Baffle ducts.

Figure 10.- Modifications to cylinder baffles.

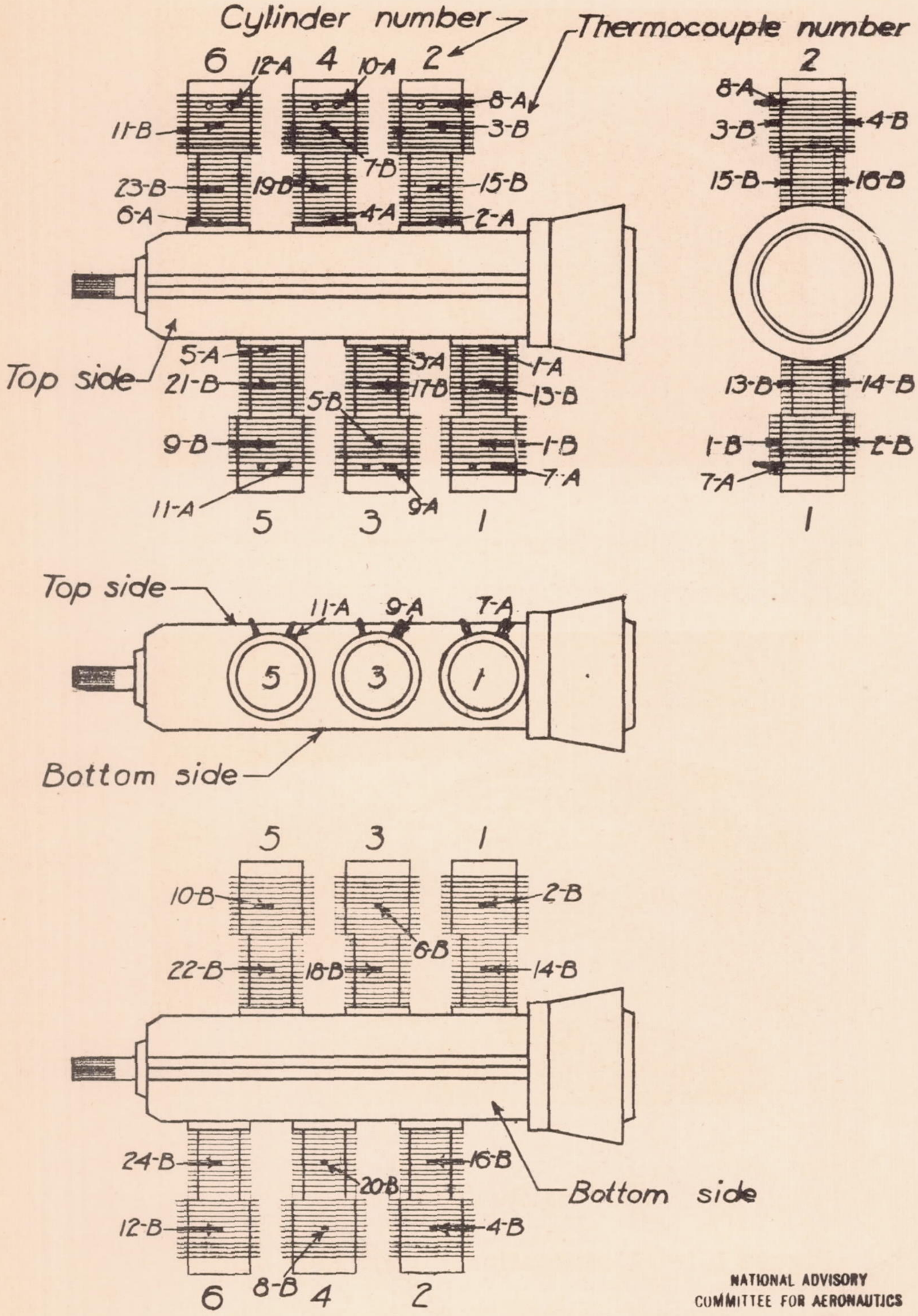


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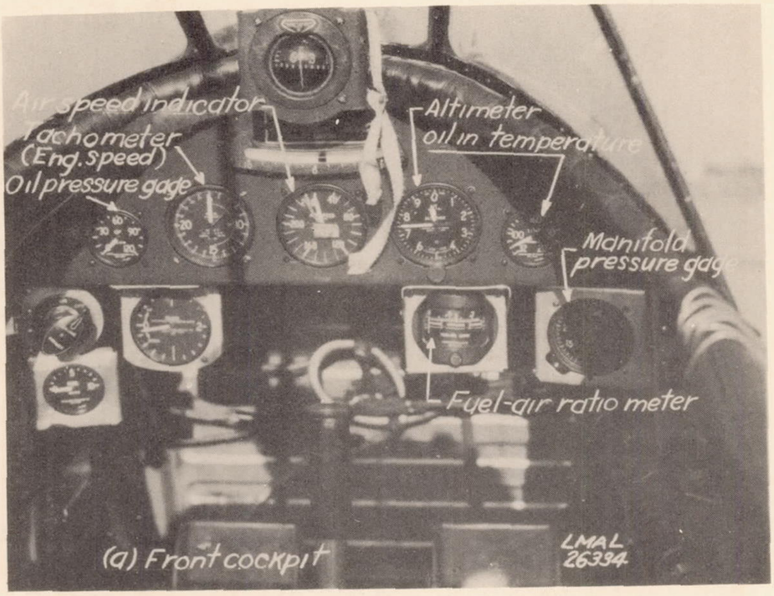
Figure 11. - Thermocouple locations for Franklin 6-AC-298 engine.



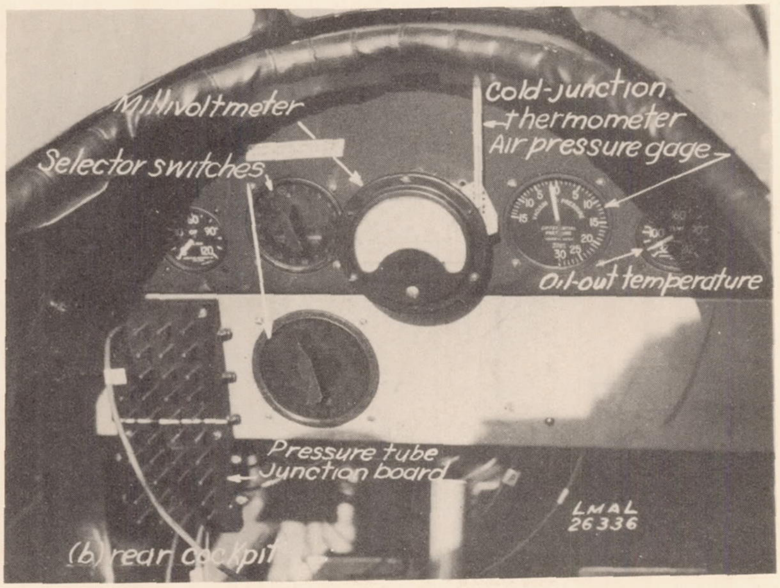


Figure 12.- Front and rear cockpits of Fleetwings model 33 airplane showing instrumentation.

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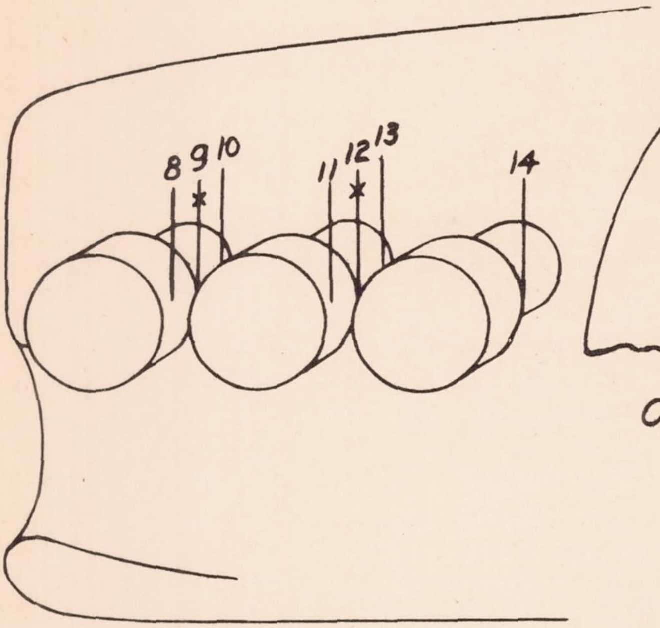
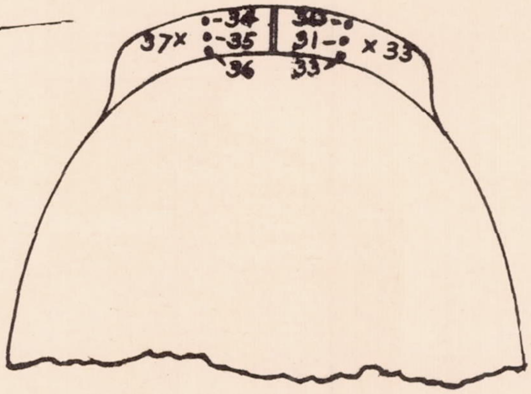


Left bank of cylinders



Outlet - looking forward

• Total pressure
× Static "
| Front baffle pressure
ǂ Rear " "

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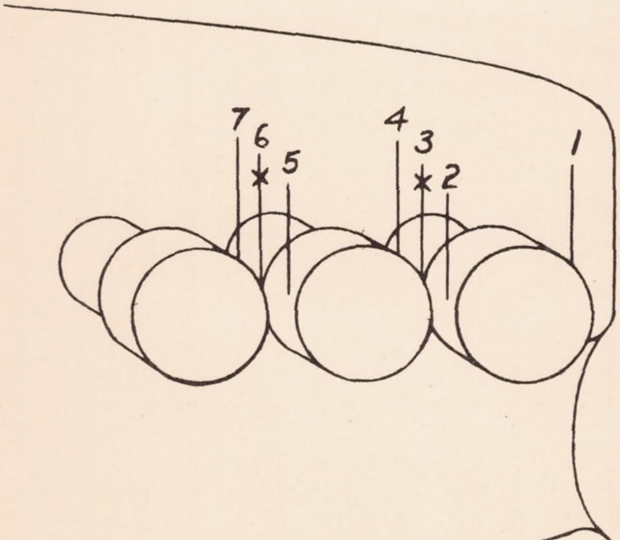
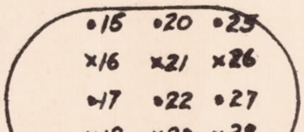
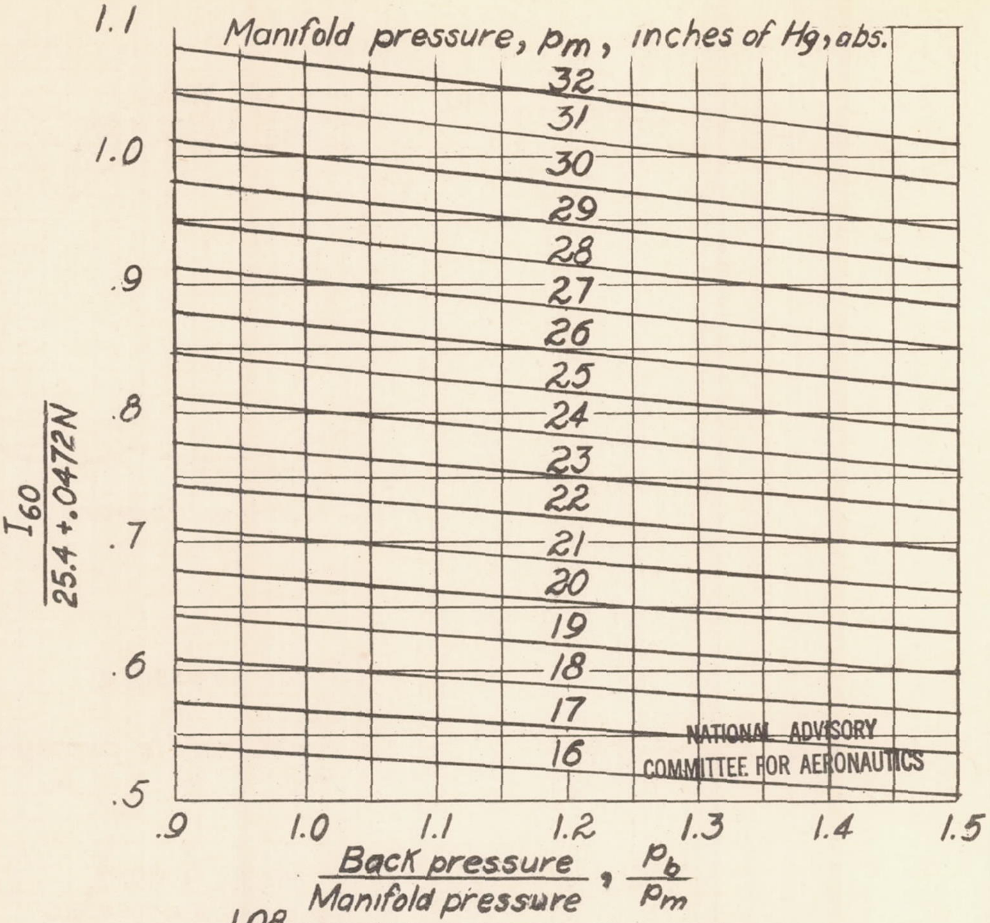


Right bank of cylinders



Inlet - front view

Figure 13.- Sketch showing location of static and total pressure tubes in modified cowling.



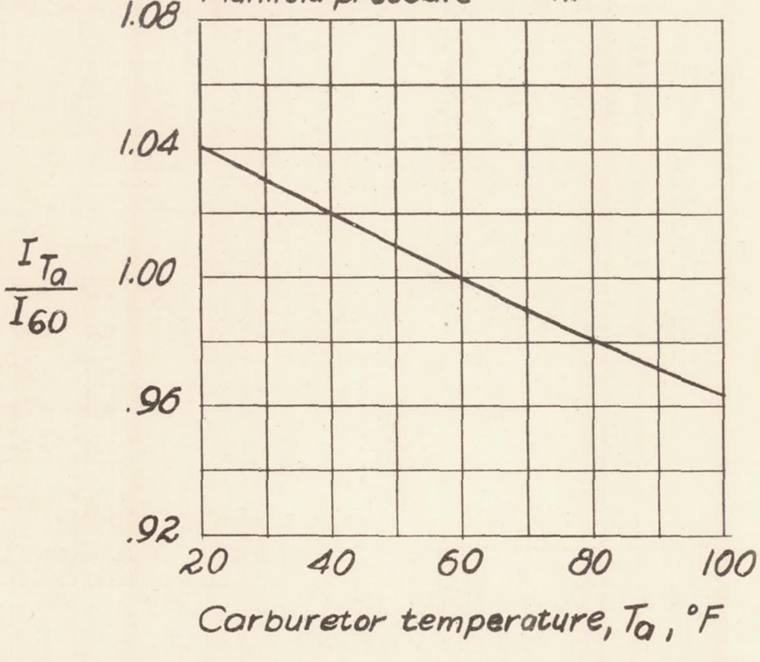


Figure 14.- Estimated indicated horsepower chart for Franklin 6-AC-298 engine.

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Figure 15.- Variation of effective gas temperature with fuel-air ratio.

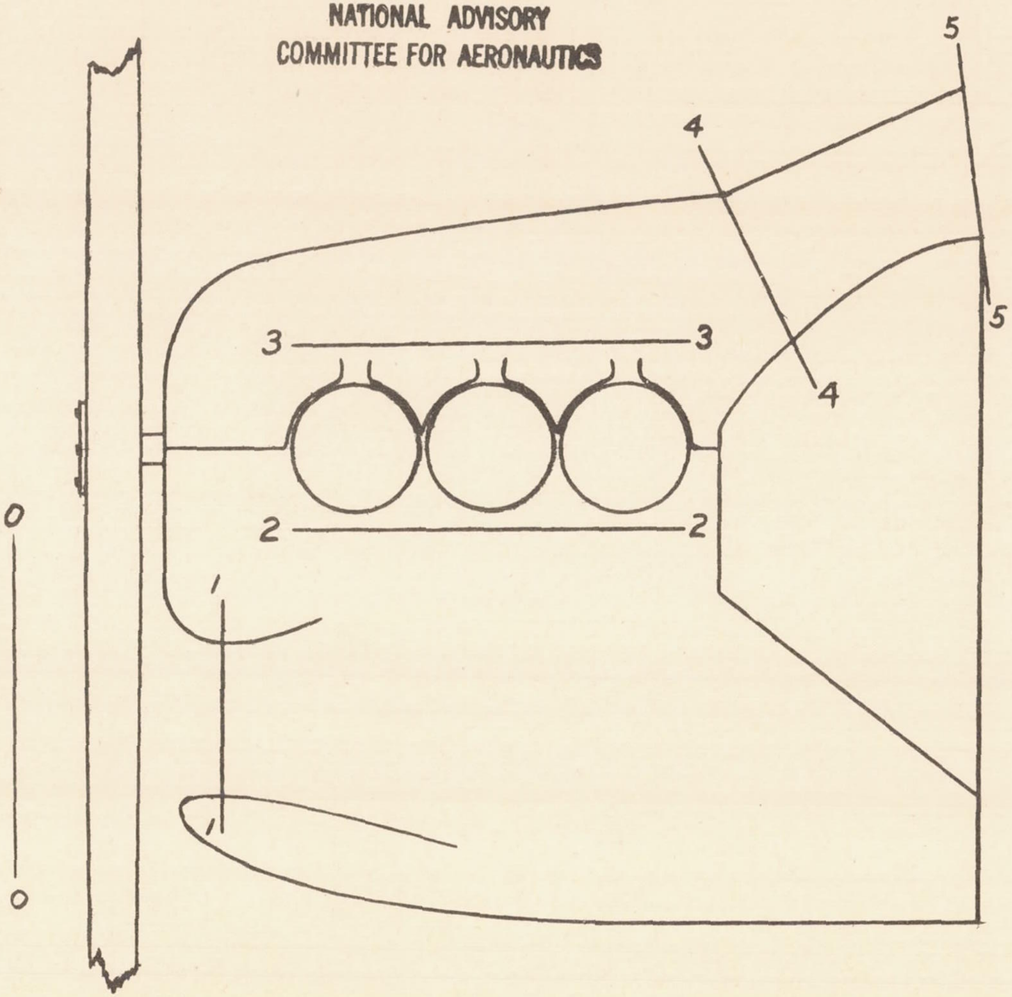
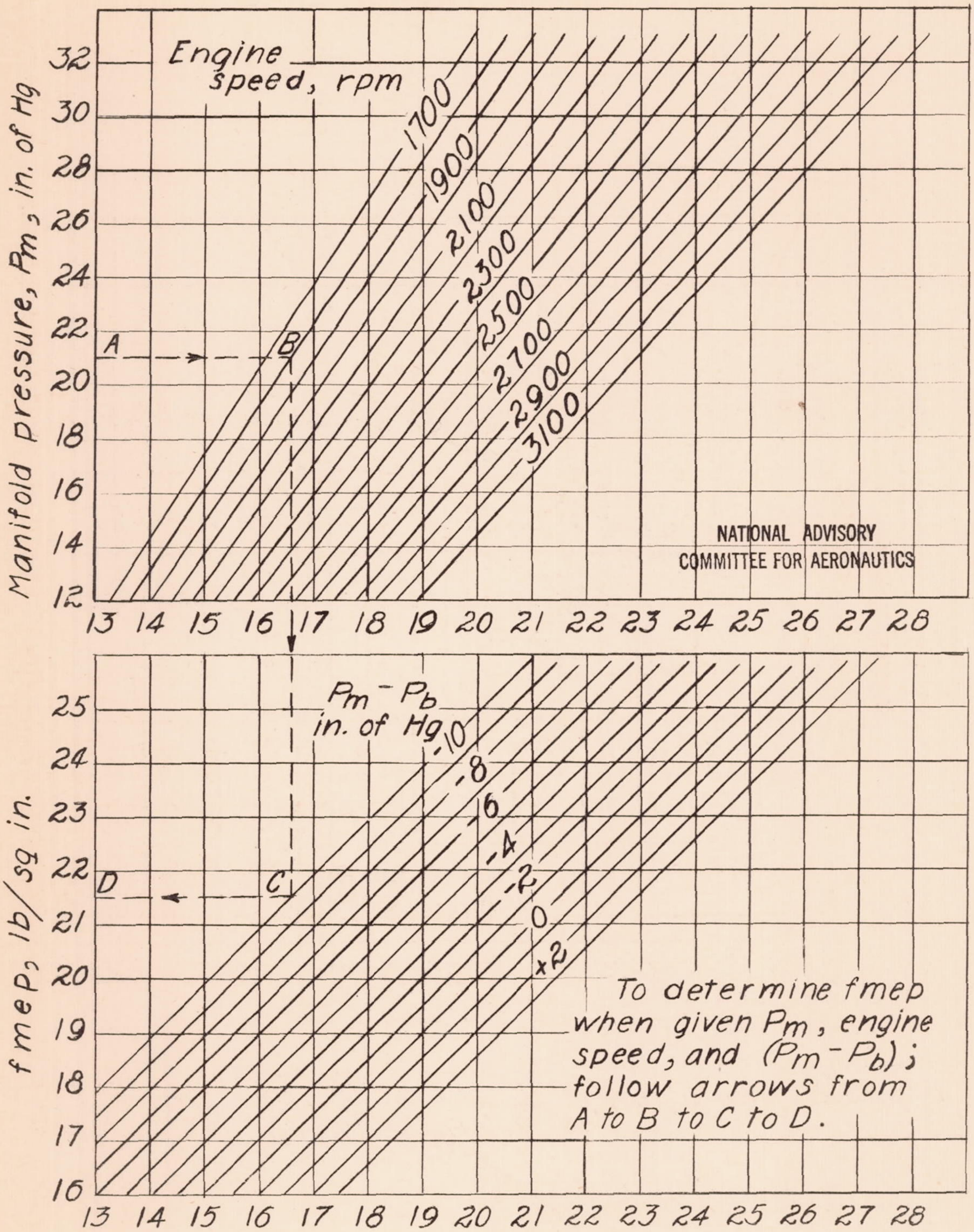


Figure 16.- Sketch of cowling showing station positions.



To determine fmep when given P_m, engine speed, and $(P_m - P_b)$; follow arrows from A to B to C to D.

Figure 17. - Estimated friction mean effective pressure chart for Franklin 6-AC-298 engine.

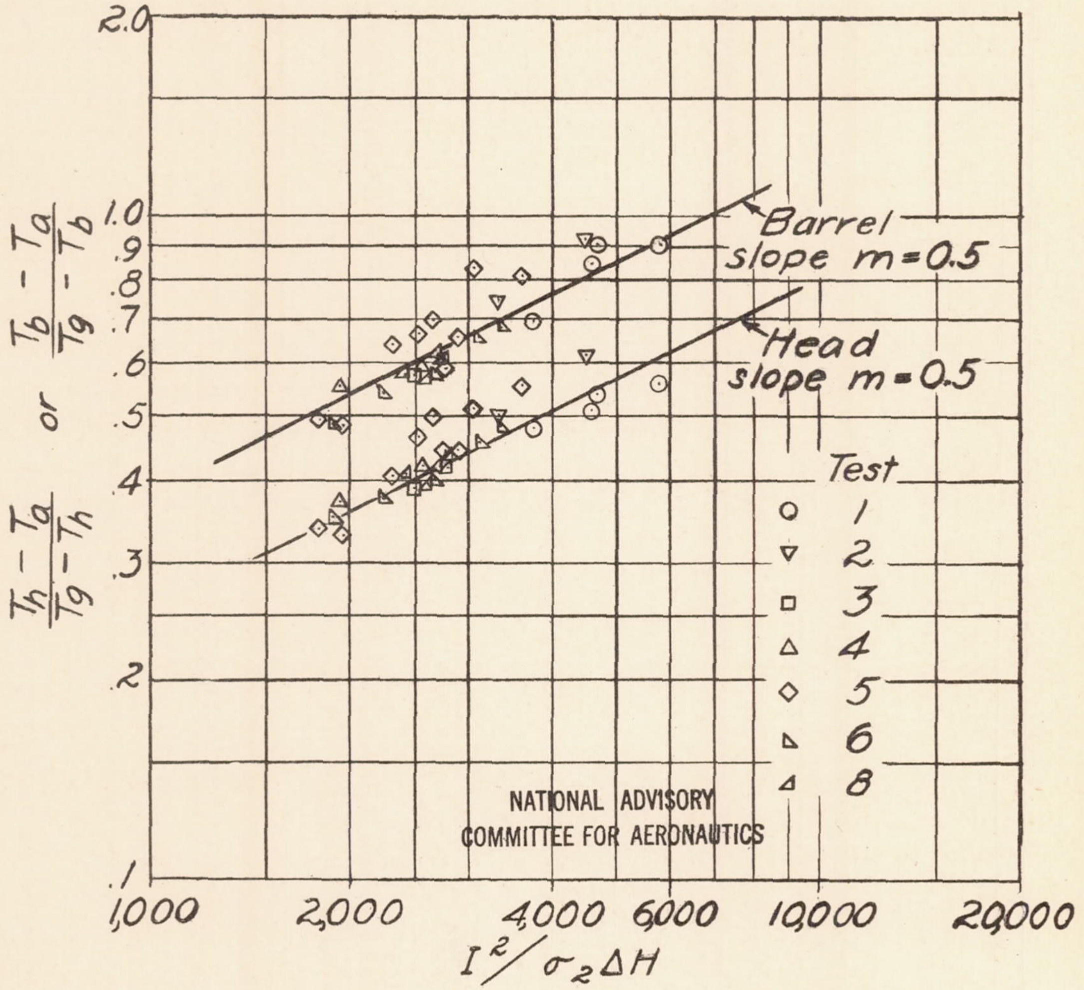


Figure 18. - Variation of $\frac{T_h - T_a}{T_g - T_h}$ or $\frac{T_b - T_a}{T_g - T_b}$ with $\frac{I^2}{\sigma_2 \Delta H}$

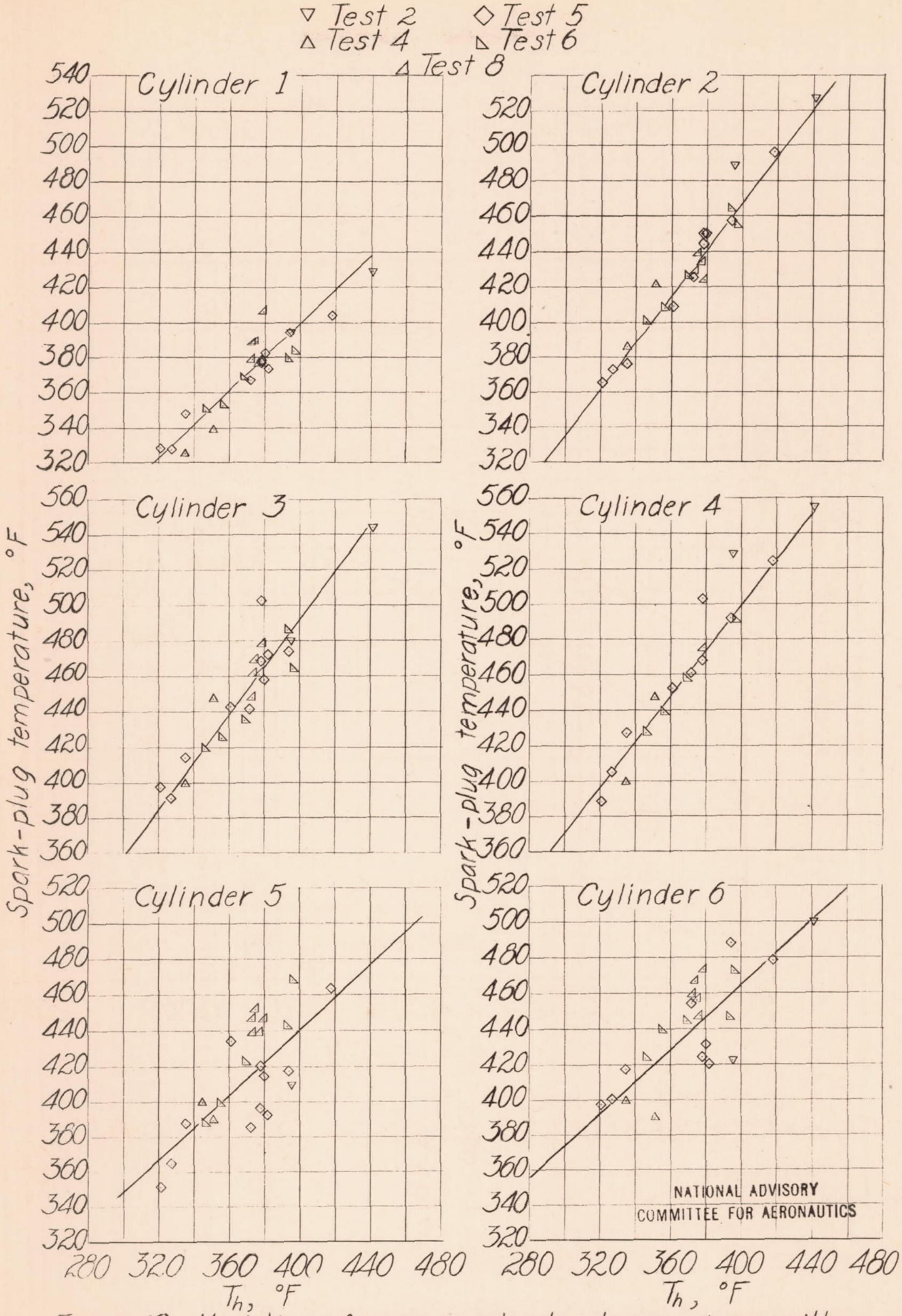


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Figure 19.- Variation of rear-spark-plug temperatures with average head temperature.

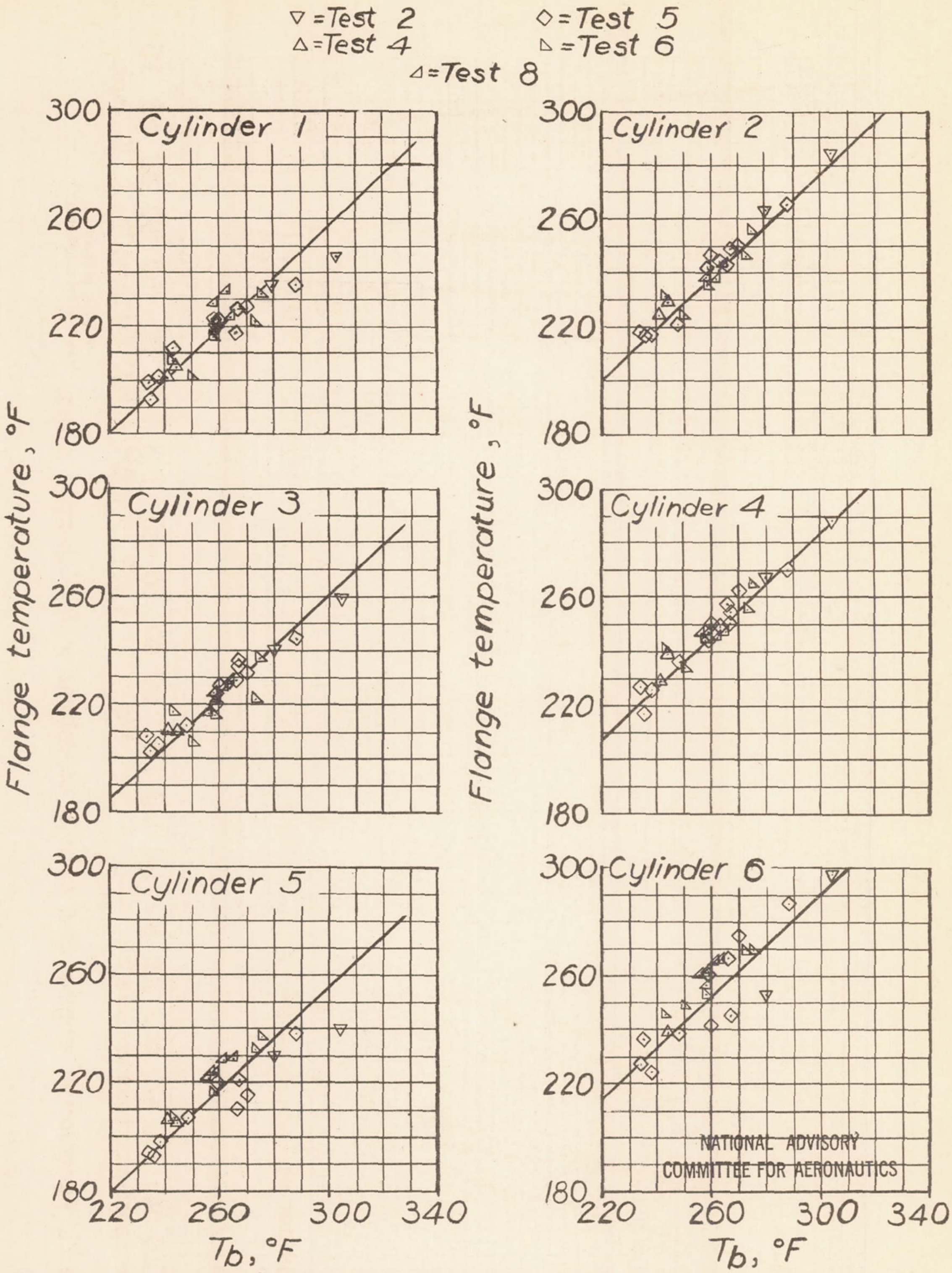

Figure 20.-Variation of cylinder-flange temperatures with average barrel temperatures.

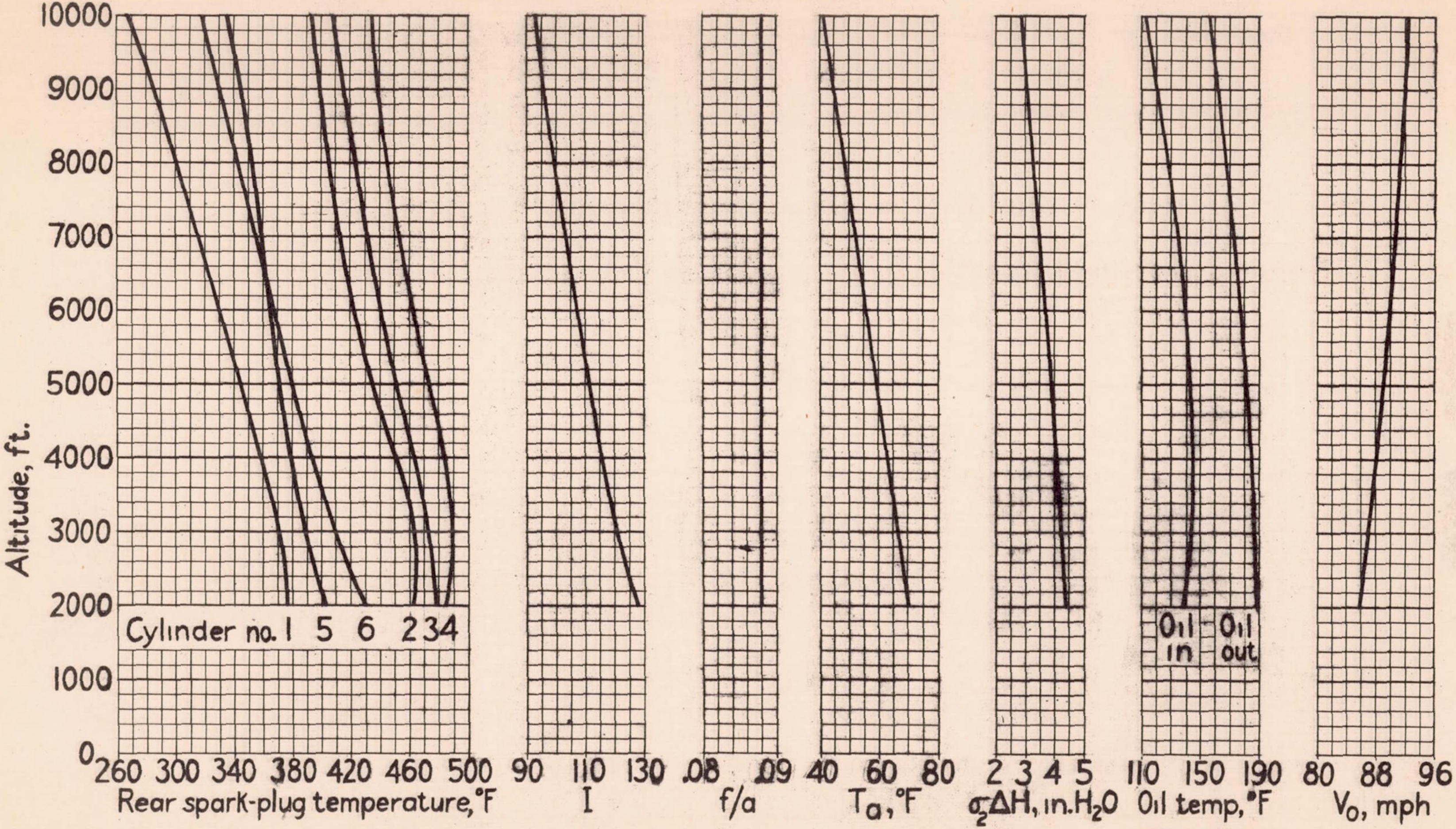

Figure 21.- Variation of engine and cooling conditions in full-throttle climb.

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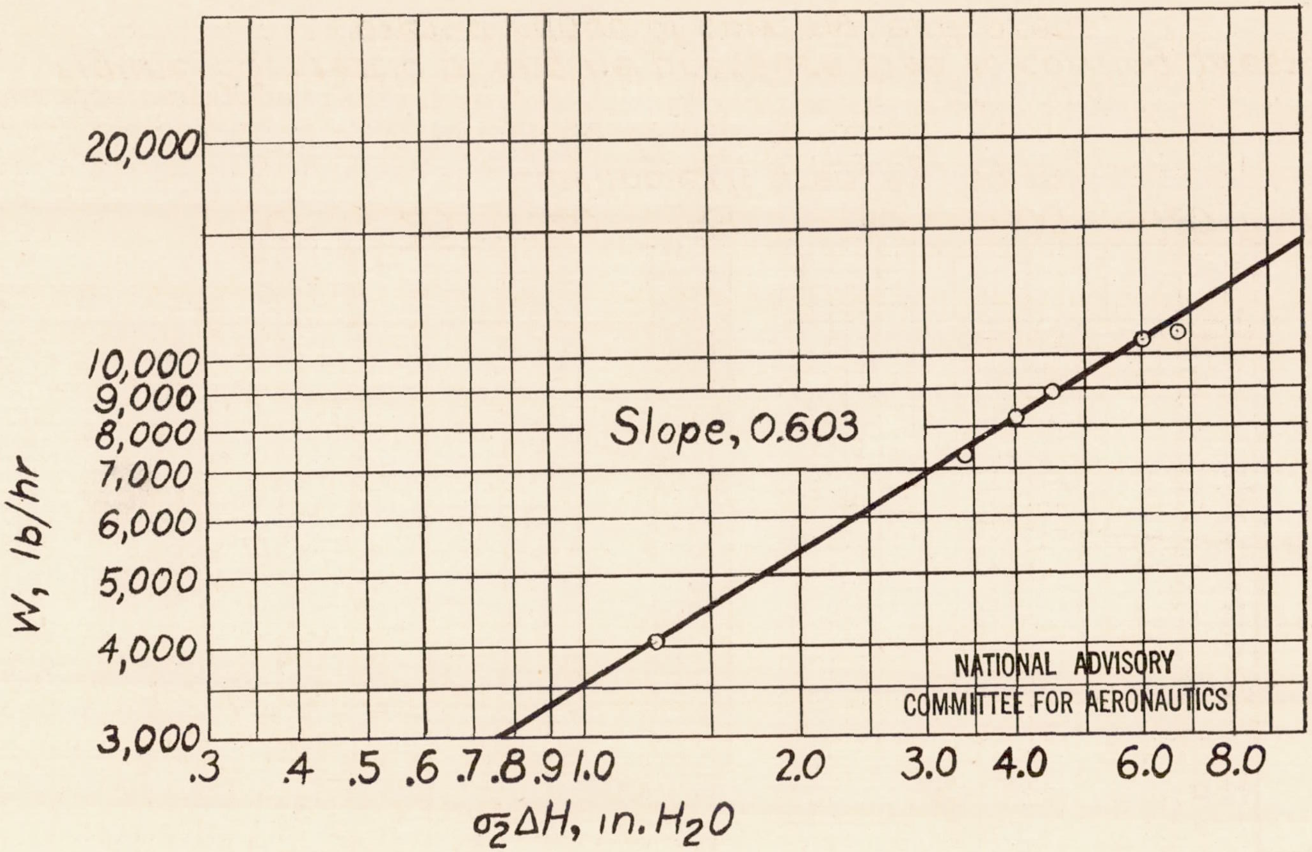

Figure 22. - Weight of cooling air flowing across engine at various cooling-pressure drops. (Area of exit, 41 square inches).

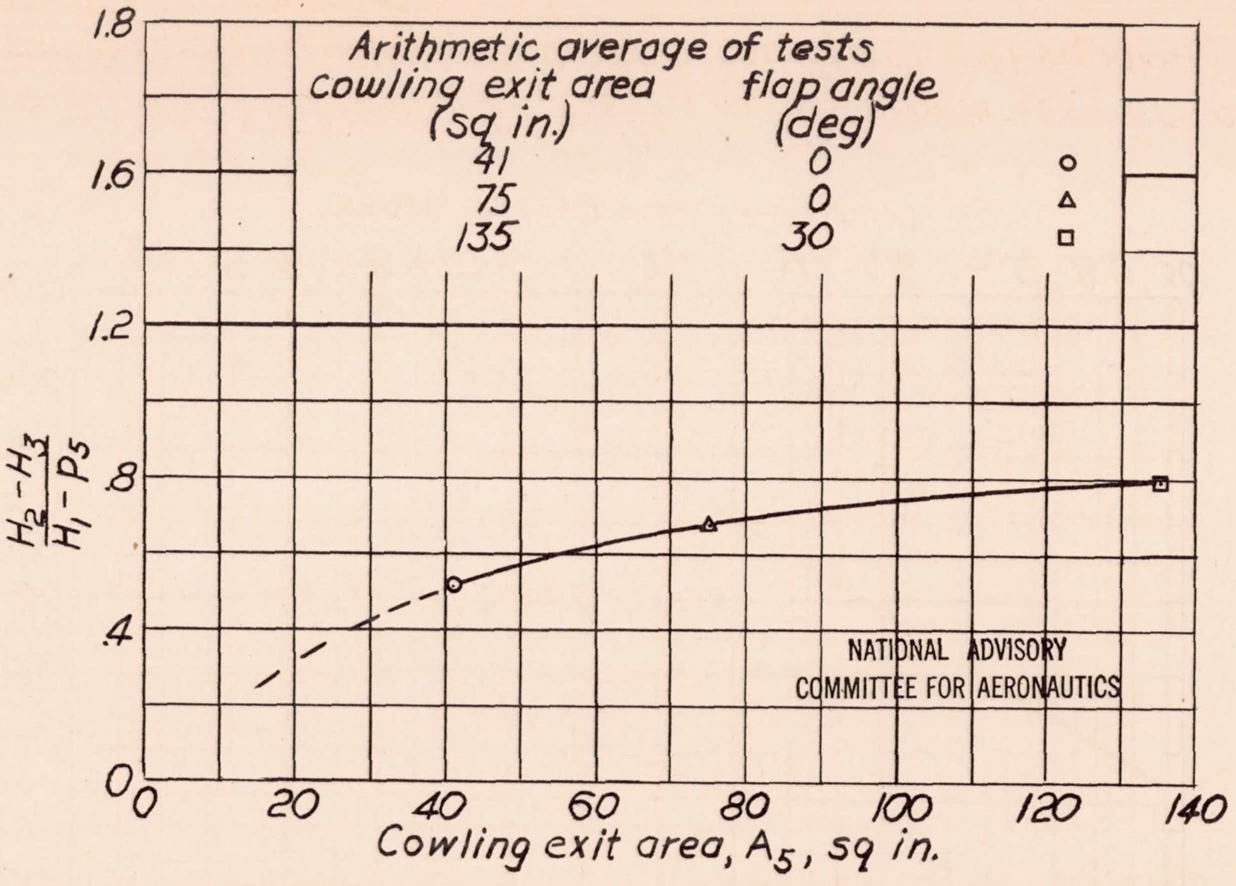

Figure 23.- Ratio of engine pressure drop to cowling pressure drop over a range of cowling exit areas.

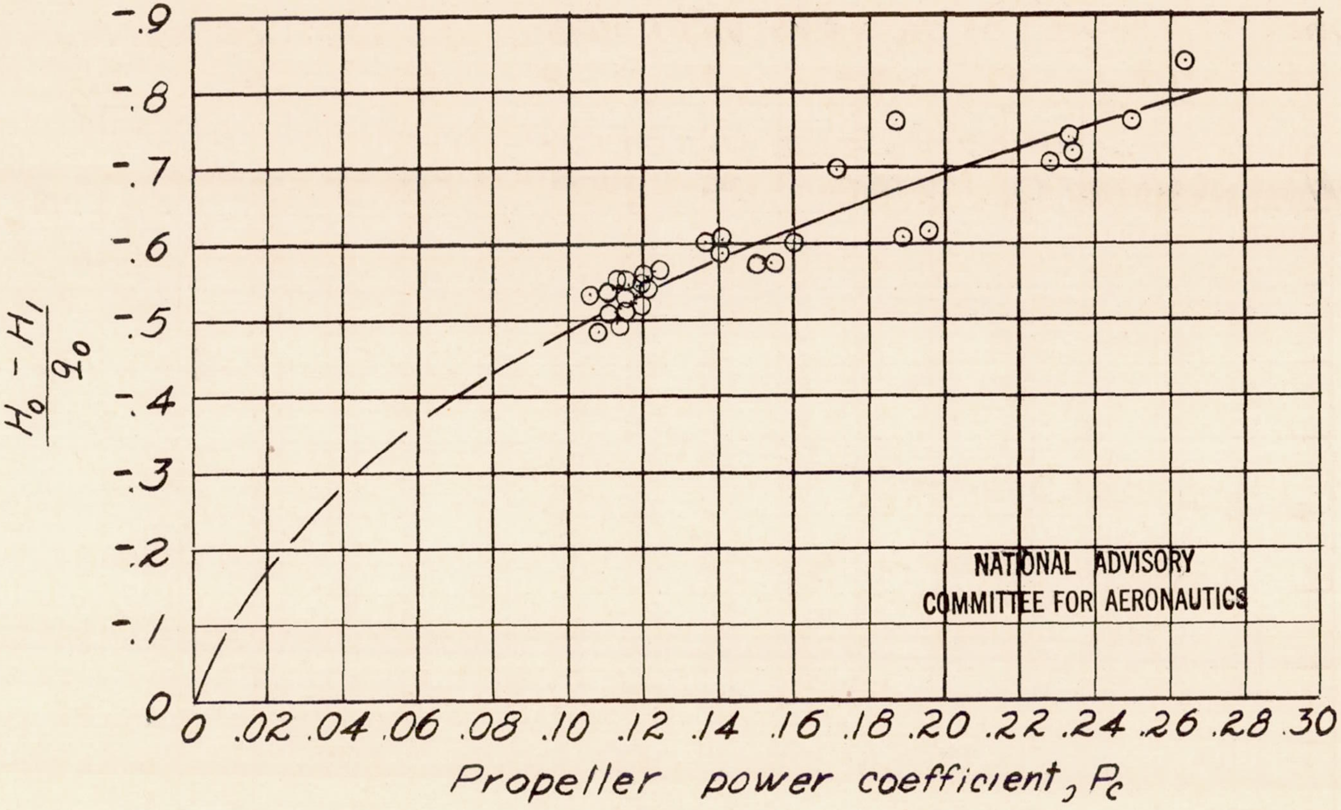

Figure 24.- Variation of $\frac{H_0 - H_1}{q_0}$ with propeller power coefficient.

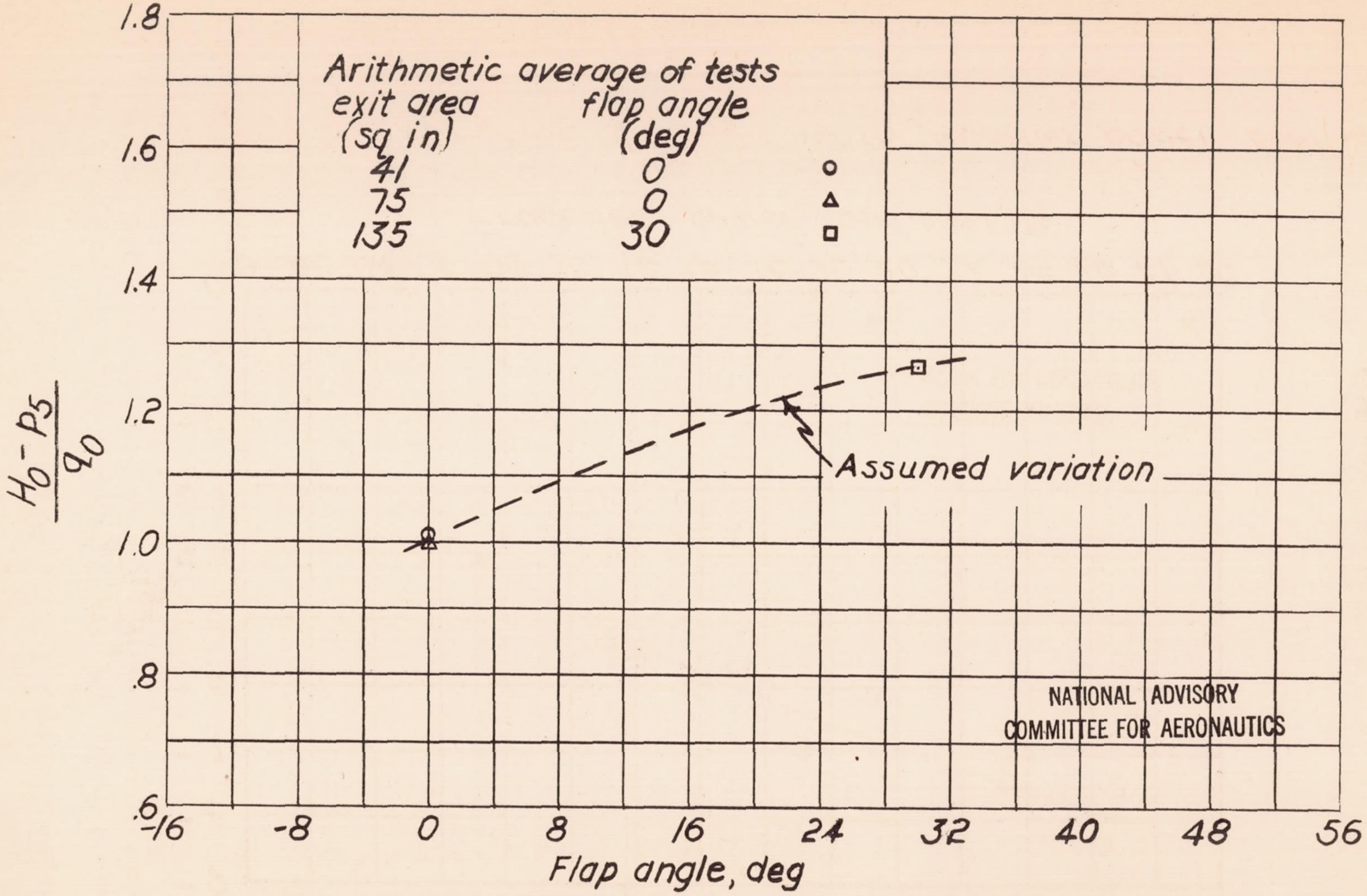

Figure 25.- Variation of $\frac{H_0 - p_5}{q_0}$ with flap angle.

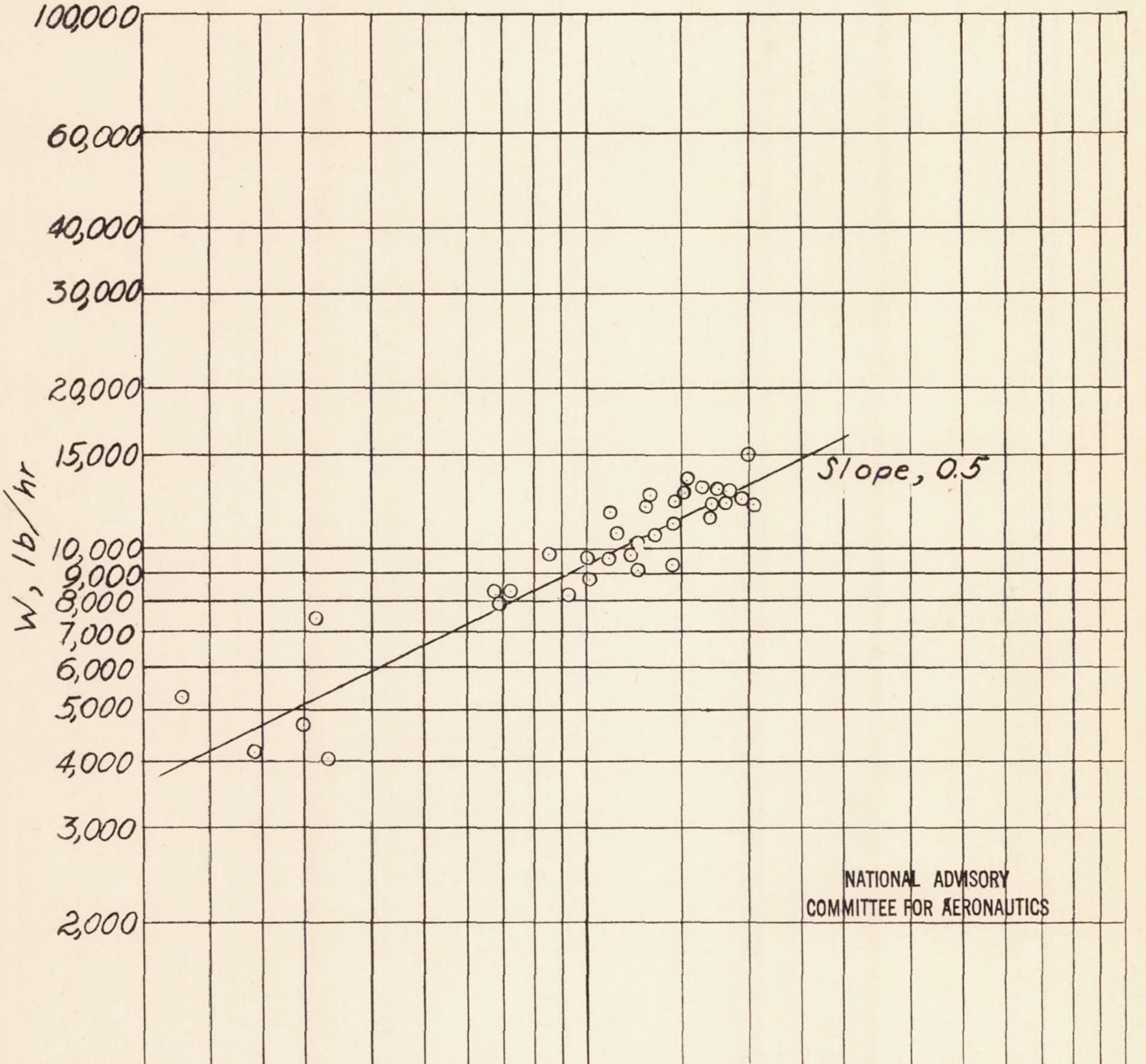

Figure 26.- Variation of total-pressure loss from cowling inlet to face of engine with cooling air flow.