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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 390

A METHOD FOR REDUCING THE TEMPERATURE OF EXHAUST MANIFOLDS

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SUMMARY

This report describes tests conducted at the Langley Memorial Aeronautical Laboratory on an "air-inducting" exhaust manifold for aircraft engines. The exhaust gases from each cylinder port are discharged into the throat of an exhaust pipe which has a frontal bellmouth. Cooling air is drawn into the pipe, where it surrounds and mixes with the exhaust gases. Temperatures of the manifold shell and of the exhaust gases were obtained in flight for both a conventional manifold and the air-inducting manifold. The air-inducting manifold was installed on an engine which was placed on a test stand. Different fuels were sprayed on and into the manifold to determine whether the use of this manifold reduced the fire hazard.

The flight tests showed reductions in manifold temperatures of several hundred degrees, to values below the ignition point of aviation gasoline. On the test stand when the engine was run at idling speeds fuels sprayed into the manifold ignited. It is believed that at low engine speeds the fuel remained in the manifold long enough to become thoroughly heated, and was then ignited by the exhaust gas which had not mixed with cooling air.

The use of the air-inducting exhaust manifold must reduce the fire hazard by virtue of its lower operating temperature, but it is not a completely satisfactory solution of the problem.

INTRODUCTION

Airplane engine-exhaust manifolds which are hot enough to ignite the fuel or lubricating oil spilled on them are a serious fire hazard. A leak in fuel or oil lines, or a crash which might not otherwise be serious, may cause fuel or oil to come in contact with the hot exhaust manifolds and start a fire.

Experiments at this laboratory in which samples of different aircraft fuels and lubricating oils have been dropped onto heated metal surfaces have shown that ignition will not occur under a temperature of about 1,250° F. for aviation gasoline, 880° F. for Diesel fuel oil, and 840° F. for lubricating oil. Kühn gives values of 1,040° F. for gasoline, 1,110° F. for Diesel oil, and 950° F. for lubricating oil. (Reference 1.) Differences in the methods used and in the samples tested may easily explain the variation in the temperatures determined.

There are three ways to prevent the exhaust manifolds from starting fires: lower the temperature of the manifold, raise the ignition temperature of the fuel and oil used, or prevent fuel or oil from coming into contact with the manifolds. All of these expedients have been tried, with varying degrees of success.

Exhaust-pipe temperatures have been lowered by using short individual stacks, either of steel or of aluminum, or by using manifolds constructed of aluminum and embodying cooling fins. However, except with inverted engines or wing engines and pusher engines where the pilot is located ahead of the engines, the short stacks do not keep the exhaust gases away from the occupants of the airplane, and at night the flames from them interfere with the pilot's vision. Finned aluminum manifolds of sections thick enough to withstand vibration are heavy and cause considerable drag.

The use of nonvolatile fuels is the most promising means for preventing airplane fires, but as yet no power plant using fuel of low volatility is available which can equal the gasoline engine on a power-weight basis.

Different locations of the tanks have been considered as a means of preventing the fuel or oil from coming in contact with the manifolds. (Reference 2.) This reference recommends droppable tanks, or that the tanks be placed where they stand the least chance of spilling their contents over the engine in case of a crash. However, there is no certainty that an airplane will remain right side up after a crash, so the advantage of any particular location for the fuel tanks is problematical.

Since the use of short exhaust manifolds is not feasible on a large number of airplanes, an investigation was made to determine possible methods of reducing the temperatures of long exhaust manifolds. For the present tests an "air-inducting" exhaust manifold was constructed and fitted to a Pratt and Whitney "Wasp" engine in a Fairchild FC2-W2 cabin airplane. Short tapered nozzles bolted to each cylinder-exhaust port discharge the exhaust gases into the throats of the exhaust stacks, which have open bell-mouthed ends pointing forward, and which are joined to the collector pipe at the rear. The high velocity of the exhaust gases in the jet creates a pressure differential sufficient to cause cooling air to flow into the exhaust pipes, where it surrounds the jets of exhaust gas and rapidly mixes with them. Temperatures of the manifold shell and of the exhaust gases were obtained in flight for both the air-inducting and the original manifolds. The air-inducting manifold was also fitted to a Wasp engine which was mounted on a test stand, and fuels were sprayed on and into the manifold to determine the probability of fire ensuing.

APPARATUS AND TESTS

Apparatus

A Fairchild FC2-W2 airplane was equipped in turn with the original and the air-inducting exhaust manifold, and was used in flight tests to determine manifold and exhaust-gas temperatures. The original manifolds are shown in Figures 1 and 2. Cylinders Nos. 1, 2, 3, 4, and 5 are connected to a manifold which carries the gases straight down below the engine. Cylinders Nos. 6, 7, 8, and 9 are connected into a manifold which discharges the gases through a slit in a tapered tail pipe, and into which is incorporated a heater for the cabin. The two manifolds are connected by a pipe which passes through the engine cowling and heats the carburetor inlet air.

The air-inducting manifold which was fitted to the right side of the engine is shown in Figure 3. The air-inducting exhaust pipes are larger than the original pipes by an amount sufficient to take care of the inducted air. Figure 4 is a cross section of one of the air-inducting pipes.

The parts of the original manifold which reached the highest temperatures were determined by running the engine at night. Several spots were found to glow redly, while the rest of the manifold surface remained black. These hot spots were situated where the exhaust gases from the individual cylinders impinged against the wall of the main manifold, and at the outside of the bend in the left manifold, just in front of the cabin-heater sleeve. Six "chromel-alumel" thermocouples were embedded in the steel manifold shell at the hottest places, and three, protected by porcelain insulators, were inserted through the steel shell into the exhaust gases. The locations of the thermocouples used are given in Table I and shown in Figures 1, 2, and 3. The air-inducting manifold did not run hot enough to make any parts of it appear red at night, but thermocouples were placed where experience with the original manifold indicated that the hot spots would be.

The thermocouples were connected in rotation to a pyrometer by means of a motor-driven switch. The instruments used to supplement the pyrometer readings were: resistance thermometers for measuring cold junction and atmospheric temperatures, oil temperature thermometer, engine tachometer, altimeter, and air-speed indicator. An observer recorded the pyrometer readings, while readings of other instruments were recorded by means of a motion-picture camera.

Tests

Each flight on which temperatures were measured was carried out as follows: first, the engine was run full throttle on the ground for 3 minutes; second, a full-throttle climb at a fairly low air speed was made for 4 minutes; third, the airplane was brought down to approximately 1,500 feet altitude and flown at full throttle in level flight for 4 minutes; and fourth, the speed was reduced to cruising and the airplane was kept in level flight for 4 minutes.

The air-inducting manifold was also fitted to a Wasp engine on a test stand, and gasoline, Diesel oil, and a hydrogenated "safety fuel" having a flash point of 135° F. were sprayed into a bell-mouthed opening of the manifold to determine the likelihood of a fire starting. Temperatures were measured at several of the points at which they were measured in flight. The tests were made for a range of speeds from idling to full throttle.

RESULTS AND DISCUSSION OF RESULTS

The temperatures observed when operating with either manifold are given in Table I. Each temperature given is the maximum obtained during the run which it represents. As was previously stated, the ground runs lasted for 3 minutes, and each condition of flight was maintained for 4 minutes. Since the temperatures became practically constant within a minute of the start of each run, the time allowed was ample to insure that they reached their maximum value. The variation in exhaust-gas temperature for successive flights with the same manifolds is probably caused by differences in the mixture ratio.

A few definite and general conclusions may be drawn from the results of these tests. The temperature measurements given in Table I show that both the exhaust-gas and exhaust-manifold temperatures can be reduced considerably by the use of the air-inducting type of manifold. The temperature of the exhaust gases from cylinder No. 2 was 1,365 to 1,465° F. with the original manifold and 590 to 680° F. with the air-inducting manifold. The exhaust-gas temperature given in Table I for cylinder No. 3 with the air-inducting manifold is not so low as for cylinder No. 2 with the same manifold. This discrepancy is due principally to the location of the thermocouple with respect to the center of the exhaust stack. The temperature of the exhaust gases is much higher in the center of the stack than near the walls because the inducted air follows the walls of the stack at first and does not immediately mix with the exhaust gases. It is believed that the exhaust manifold shown in Figure 3 could be improved by using pipes of larger diameter between the cylinder and the main stack and by having these pipes connect with the main stack at some angle less than 90°. With the above modification the velocity of the exhaust gases in the stacks would be reduced and they would be directed so that they could not penetrate the layer of cold air and impinge upon the walls of the exhaust manifold.

Lower cylinder-head temperatures can be obtained with these manifolds because the air is rapidly removed from the rear of the cylinder, resulting in increased flow over the cylinder head. In these tests the reduction in cylinder-head temperature, as shown by thermocouples 10 and 11, Table I, varied from 20 to 90° F., depending on the location and the operating conditions.

Although these manifolds are more noisy than the original manifolds the noise does not compare in intensity with the propeller noises. They are less noisy than the short exhaust stacks now in use by the military services. For night flying the type of air-inducting manifold tested would be more desirable than the short stacks because the pilot's vision would not be impaired by the glare of the continuous stream of hot exhaust gases.

Tests were also made to determine if the air-inducting manifold created any appreciable back pressure at the exhaust owing to the area of the opening in the short stack inside of the bellmouth being less than the area of the exhaust port. These tests were made by running the engine at full throttle on the ground with the air-inducting manifold on the right side and the original manifold on the left side. Each cylinder was then cut out in turn by removing the ignition wires, to determine whether the cylinders with the air-inducting manifold or with the original manifold were giving the greater power. Although this method is subject to the error introduced by the difference in output of each cylinder, it was nevertheless interesting to note that the cutting out of the cylinders served by the air-inducting manifold gave consistently a slightly greater decrease in engine speed than was obtained when the cylinders served by the original manifold were cut out.

The principal object of these tests was to reduce the exhaust-gas and manifold temperatures. Therefore, no attempt was made to streamline the air-inducting manifold, which was of much greater diameter than the original. A flight test was conducted, however, to determine the maximum air speed obtainable when a complete set of air-inducting manifolds was used, and a similar test was made with the original manifolds. In these tests, which were made the same day under similar conditions, speeds of 126 miles per hour at 1,815 to 1,820 revolutions per minute and 124 miles per hour at 1,800 revolutions per minute were obtained with the original and the air-inducting manifolds, respectively. This small difference must be attributed to the difference in resistance or to experimental error either in these flights or in the previous test showing the effect of exhaust back pressure.

The tests in which fuels were sprayed into the manifold showed that the fuels would not ignite when in contact with the manifold or when sprayed into the manifold with the engine running above a speed of 900 revolutions per minute. At lower speeds, however, all the tested fuels ignited when sprayed into the manifold. At the low engine speeds the fuel probably remained in the manifold long enough to become thoroughly heated, and the flame from the exhaust-stack nozzles ignited it. It was noted that Diesel oil and the high-flash "safety fuel", which were slower to vaporize, were more readily ignited than gasoline. The fuels could not have been ignited by coming in contact with the exhaust nozzles, for a thermocouple placed on a nozzle for one test showed a maximum temperature of only 460° F.

CONCLUSIONS

1. The maximum temperature of the air-inducting exhaust manifold is from 200° to 400° F. lower than that of the original manifold, and there is an even greater reduction in the temperature of the gases in the manifold.

2. Although the temperature of the air-inducting exhaust manifold is well below the ignition temperature of fuel or oil, it is still possible for fuel to be ignited by the exhaust gases if it finds its way into the manifold when the engine is throttled sufficiently.

3. The air-inducting manifold is not so effective a silencer of exhaust noises as the original manifold.

4. There was very little change in the high-speed performance of a Fairchild FC2-W2 airplane when equipped with the air-inducting exhaust manifold.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 25, 1931.

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TABLE I

EXHAUST GAS AND EXHAUST MANIFOLD TEMPERATURES (°F.)

		Original manifolds				Air-inducting manifolds Cylinders Nos. 2, 3, 4, and 5			
Thermocouple No.	Location	Full throttle on ground	Full throttle in climb	Full throttle level flight	Cruising level flight	Full throttle on ground	Full throttle in climb	Full throttle level flight	Cruising level flight
1	In exhaust gases from cylinder No. 2.	1365	1365	1385	1465	605	680	665	590
2	In exhaust gases from cylinder No. 8.	1365 1270 1300 1440	1380 1280 1310 1450	1435 1245 1330 1425	1480 1400 1410 1490				
3	In exhaust gases from cylinder No. 3.					950	1015	1020	985
4	In exhaust gases in tail pipe of original manifold, left side.	1050	1050	1130	1255				
5	In shell of exhaust stack between cylinders Nos. 2 and 3.	850	775	780	835	540	540	505	430
6	In shell of exhaust stack in back of cylinder No. 3.	940 965	940 905	960 830	1020 660				
7	In shell of exhaust stack between cylinders Nos. 4 and 5.	720	690	725	675				
8	In shell of exhaust stack between cylinders Nos. 3 and 4.					550	510	505	350
9	In shell of exhaust stack between cylinders Nos. 7 and 8.	860 740	780 770	680 725	750 740				
10	In open surface at rear of exhaust passage of cylinder head No. 3.	430	400	390	390	340	355	335	310
11	At base of fin at rear of exhaust passage of cylinder head No. 3.	465	425	400	400	395	405	370	350
12	In shell of exhaust pipe from cylinder No. 5.					420	380	345	310

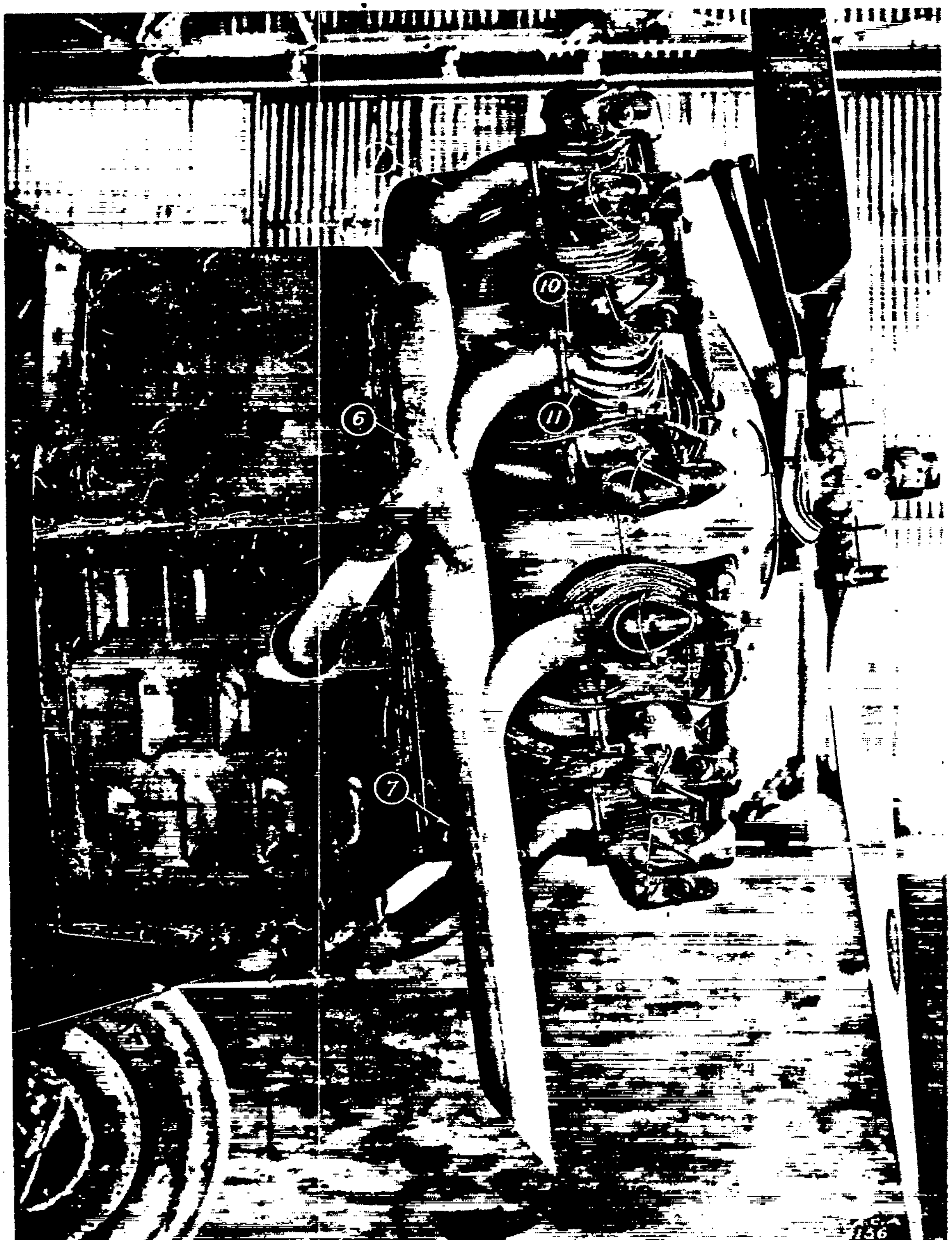

Fig.1 Right side of Pratt and Whitney "Wasp" engine with original exhaust manifold.

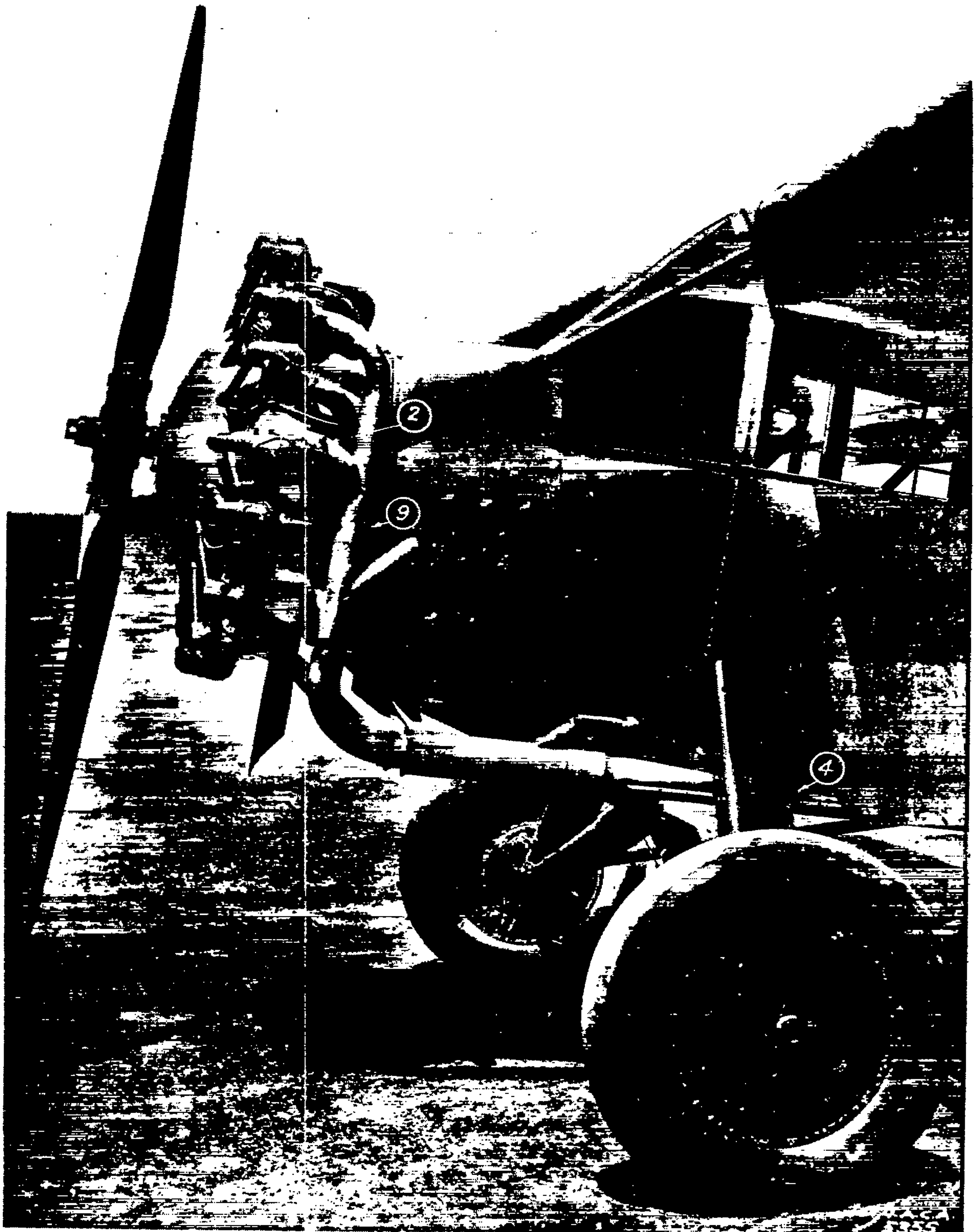

Fig.2 Left side of Pratt and Whitney "Wasp" engine with original exhaust manifold.

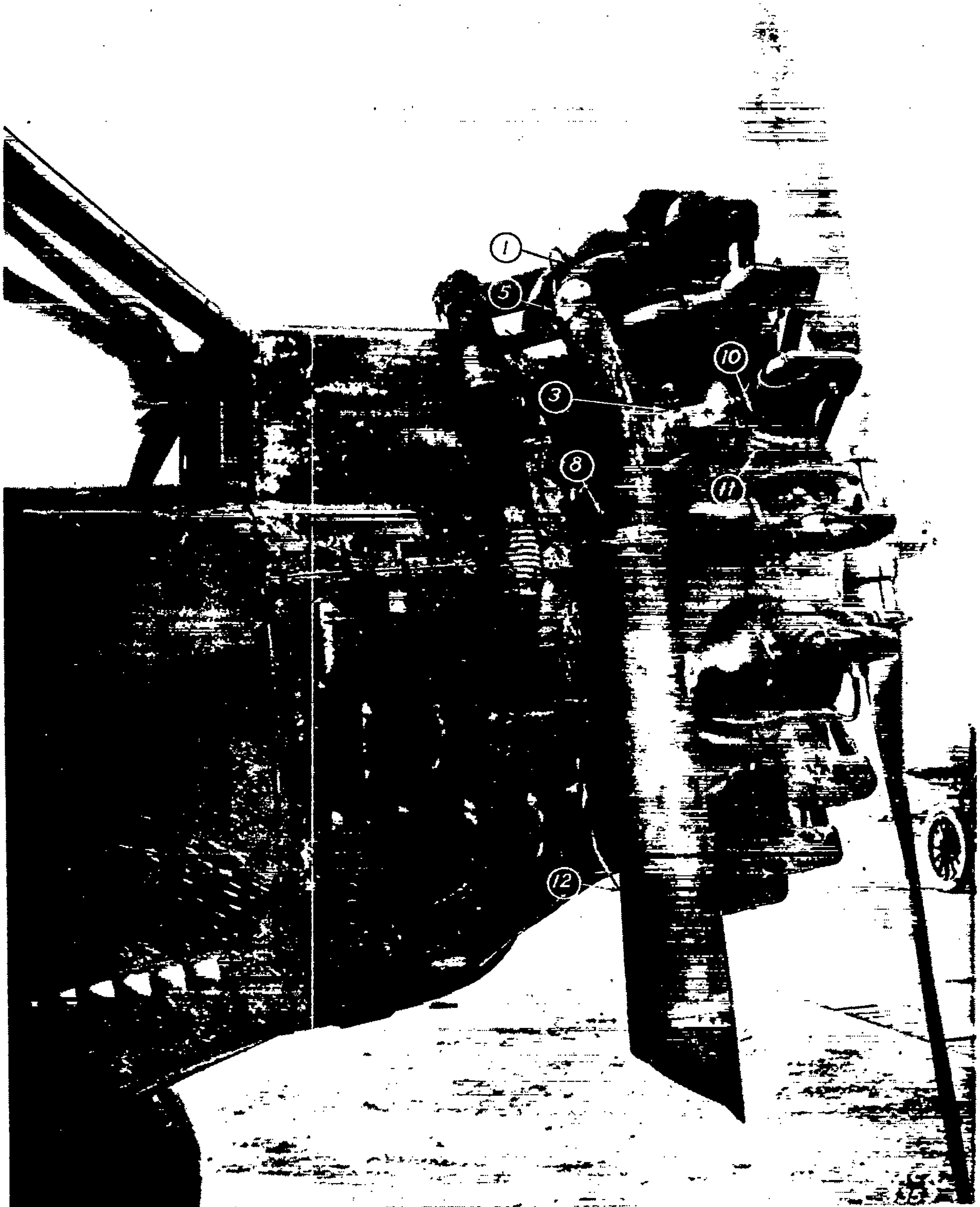

Fig.3 Right side of Pratt and Whitney "Wasp" engine with air-inducting exhaust manifold.

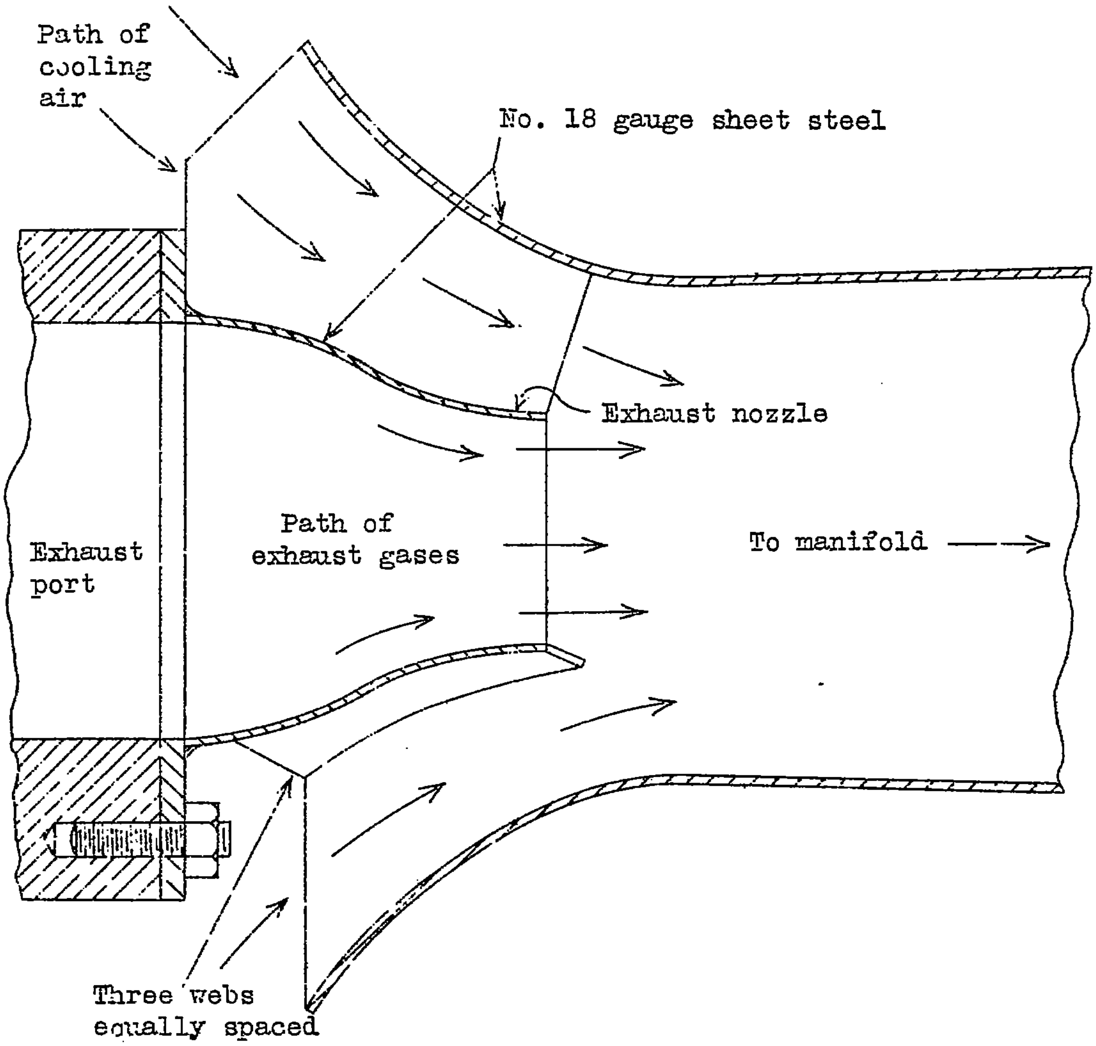

Fig. 4 Cross section of air-inducting exhaust pipe.