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FLIGHT TESTS OF EXHAUST-GAS JET PROPULSION

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SUMMARY

Flight tests were conducted on the XP-41 airplane, equipped with a Pratt & Whitney R1830-19, 14-cylinder, air-cooled engine, to determine the increase in flight speed obtainable by the use of individual exhaust stacks directed rearwardly to obtain exhaust-gas thrust. Speed increases up to 13 miles per hour at 20,000 feet altitude were obtained using stacks having an exit area of 3.42 square inches for each cylinder. A slight increase in engine power and decrease in cylinder temperature at a given manifold pressure were obtained with the individual stacks as compared with a collector-ring installation. Exhaust-flame visibility was quite low, particularly in the rich range of fuel-air ratios.

INTRODUCTION

The high speed of present-day airplanes suggests the possibility of obtaining appreciable power by means of jet propulsion. The gas in the cylinder of an internal combustion engine, at the time the exhaust valve opens, is at a pressure considerably higher than atmospheric, and the largest part of this gas is discharged through the exhaust valve with a velocity of the order of that of sound. In the usual exhaust installation the gases are discharged into a collector where the largest part of this velocity is lost at the bends and at sudden enlargements of the exhaust pipes.

Oestrich (reference 1) presents the results of computations to show that considerable thrust horsepower can be obtained at high airplane velocity by discharging the exhaust gas rearwardly of the airplane, directly from the exhaust port of the separate cylinders. This result was substantiated by a more complete analysis made at the NACA and the large theoretical exhaust thrusts obtained indicated that tests to determine the actual exhaust thrust were justified.

Preliminary tests were made on a Pratt & Whitney R1340E engine provided with individual exhaust stacks mounted on a thrust stand, in which the static thrust provided by the rearward discharge of exhaust gas was measured. The thrust horsepower at various airplane velocities calculated from these measurements agreed reasonably well with the values obtained from the analysis and indicated that a considerable increase in flight speed should be obtained by utilizing this exhaust-gas thrust.

To determine the increase in flight speed at various altitudes experimentally, and to investigate the problems associated with an individual exhaust-stack installation such as exhaust-flame visibility, fire hazard, noise, and the danger of carbon-monoxide poisoning of the flight personnel, it was decided that flight tests should be conducted.

This report presents the results of flight tests on the XP-41 airplane to determine the increase in flight speed that may be obtained by discharging the exhaust gas rearwardly through individual stacks.

The tests were made during March and April 1940, at the Langley Memorial Aeronautical Laboratory at Langley Field, Va.

APPARATUS AND TESTS

The tests were made on the XP-41 airplane (fig. 1(a)), a single-seat Seversky pursuit airplane equipped with a Pratt & Whitney R1830-19, 14-cylinder, two-row radial engine. The engine is provided with a two-speed auxiliary blower in addition to the main blower, and had a critical altitude of 20,000 feet.

Figure 1(b) shows the exits of the collector ring. It is noted that the discharge is substantially downward. The collector-ring installation is that originally provided on the airplane, with the exception that one exit has been moved toward the center of the fuselage to avoid trouble experienced from the discharge of that stack into the oil-cooler duct.

Figure 2 shows the installation with individual exhaust stacks. The stacks from the cylinders at the top of the engine were brought down and the gas discharged from the side of the fuselage in order to avoid discharging in the direction of the cockpit cover. Because of the lack of space at the cowling exit, the stacks of the top cylinders, nos. 1 and 13, were connected to a common exit having substantially the same area as an individual stack. Cylinders nos. 2 and 4 were similarly joined to a common exit on the opposite side of the fuselage. These cylinders were chosen because their exhaust events do not overlap. The remaining cylinders had individual exhaust stacks. The end of each exhaust stack was flattened into a substantially elliptical shape in order to decrease the radial distance that exhaust stacks extended from the fuselage. The inside cross-sectional area of the stack decreased from 4.07 square inches at the round section to 3.42 square inches at the exit. A pattern used for the construction of these stacks is shown in figure 3. The exhaust stacks emerged from the cowling through holes cut in the cowling flaps. Clearance was provided to allow approximately 1/8-inch relative movement of the stacks and cowling.

After the tests with the individual stacks, a portion of each stack was removed and a nozzle having an area of 1.77 square inches was welded in its place. The form of the nozzles is shown in figure 3. The nozzles installed in place are shown in figure 4. Where required, the cowling flaps were replaced by new flaps with holes cut for clearances between the flaps and nozzles of approximately 1/8 inch. No reduction was made in the exit area of the stacks for the cylinders connected in pairs (nos. 13, 1, 2, and 4), because of the possible danger of overheating and detonation arising from too much resistance to the exhaust-gas flow.

The following are the exit areas of the various installations:

		Exit area per cylinder (sq in.)
A	collector ring	2.81
B	individual stacks	[a]3.42
C	individual stacks	[a]1.77

[a]Except for cylinders nos. 13, 1, 2, and 4, which were connected in pairs to stacks having exit areas of 3.42 sq in. per stack.

The two individual stack installations, B and C, will be designated by the exit areas, 3.42 and 1.77 square inches, respectively.

The engine torque was measured in flight by a Pratt & Whitney torque dynamometer. The engine speed was measured by a calibrated electrical tachometer. The airplane speed was measured by an air-speed head mounted on a boom attached to the wing. This air-speed head was calibrated by flying alongside a Lockheed 12 airplane, for which the air-speed installation had been previously calibrated using a towed static pressure bomb. The altitude was measured with a Kollsman sensitive altimeter and recorded by the pilot. A statoscope was installed and operated during each period of test. The statoscope deflection and the air speed were recorded photographically, providing a continuous graph when the equipment was actuated. Motion pictures were taken of the pressure gage of the torque dynamometer, a clock, and the tachometer indicator. When test conditions were stabilized, eight series of photographs of about 2 seconds' duration each were taken at 15-second intervals by the manual closing of an electrical circuit by the pilot. Each of the 2-second motion-picture records contained approximately 25 frames. The averages of the eight series of engine speed, air speed, and torque readings were taken to represent the test conditions.

Rear spark-plug gasket temperatures for two cylinders were read by the pilot, and the higher temperature, that of no. 5 cylinder, was recorded. The manifold pressure, carburetor-air temperature, cylinder-head temperature, oil temperature, cabin temperature, indicated atmospheric temperature, tachometer magneto temperature, and engine rpm were recorded by the pilot immediately after the last automatic record of each run. The indicated atmospheric temperature was also determined at 120 miles indicated air speed, and the true atmospheric temperature determined by extrapolating a curve of temperature against velocity head to zero air speed.

In the absence of a reliable instrument for measuring air-fuel ratio, the mixture was adjusted by the pilot for maximum power at part throttle, and by the automatic mixture control at full throttle.

All tests were made at an approximate engine speed of 2550 rpm.

Flights were made at the following conditions:

	Altitude (ft)			
Collector ring	10,000	15,000	17,000	20,000
Individual stacks	10,000	--	17,000	20,000
Individual stacks with nozzles	10,000	--	17,000	20,000

At each altitude the throttle was varied from full-open throttle to part throttle, and complete data taken for each setting.

A carbon-monoxide meter was placed in the cockpit of the airplane with individual stacks prior to the main flight tests. Carbon-monoxide concentrations were measured in flight with the cockpit cover closed with inlet manifold pressure of 30 inches Hg for level flight, and for climb at 150 miles per hour indicated air speed, and in a glide with 10 inches Hg inlet manifold pressure with the cockpit cover opened.

After the completion of the tests with the individual stacks with 1.77 square-inch-exit areas, a portion of the nozzles was removed in order that no part of the nozzle projected into the air stream, thus providing a more streamlined installation. Three temperature-sensitive paints which change color at 288°, 338°, and 734° F, respectively, were applied to portions of the fuselage in proximity of the exhaust gas stream. The engine was operated on the ground at a manifold pressure of 30 inches Hg at 2500 rpm to determine if any appreciable heating of the fuselage occurred.

Visibility tests of the flame from the individual stacks were made at night at a manifold pressure of 30 inches Hg at about 2400 rpm. The mixture was varied from full rich to lean, and photographs were obtained with the mixture control set at the lean position for cruising.

METHODS

The various tests of different exhaust conditions were made at the same pressure altitudes but because of differences in atmospheric temperature, a slight difference in density occurred. Correction of the data to a common density for each pressure altitude was made in the following manner. Power-speed data for a normally propelled airplane may be correlated for different atmospheric densities by plotting

$$\sigma^{\frac{1}{2}} \text{ bhp against } \left(\sigma^{\frac{1}{2}} V\right)^3$$

where

σ is the atmospheric density ratio relative to standard sea-level density

and

V the airplane speed

This correlation is obtained by noting that if the well-known equation for the drag horsepower of an airplane,

$$\text{Drag hp} = K_1 \sigma V^3 + \frac{K_2}{\sigma V}$$

is multiplied through by $\sigma^{\frac{1}{2}}$, there results

$$\sigma^{\frac{1}{2}} \text{ drag hp} = K_1 \left(\sigma^{\frac{1}{2}} V\right)^3 + \frac{K_2}{\left[\left(\sigma^{\frac{1}{2}} V\right)^3\right]^{\frac{1}{3}}}$$

Thus $\sigma^{\frac{1}{2}} \text{ drag hp} = f\left(\sigma^{\frac{1}{2}} V\right)^3$.

If, in addition, it is assumed that the propeller efficiency is constant, then there may also be written

$$\sigma^{\frac{1}{2}} \text{ bhp} = f\left(\sigma^{\frac{1}{2}} V\right)^3 \qquad (1)$$

Corrections were made to standard density altitude by multiplying the observed power and airplane speed by

$$\left(\frac{\sigma}{\sigma_{std}}\right)^{\frac{1}{2}}$$

where σ_{std} is the standard relative density corresponding to the test pressure altitude.

The engine power was corrected for the power associated with accidental acceleration and climb. A propeller efficiency of 0.85 was assumed for this correction. The acceleration was calculated from the air-speed records, and the rate of climb from the statoscope records. In each test an average acceleration and rate of climb were obtained for the complete 2-minute run. The recorded air speeds were corrected for compressibility.

The collector-ring installation discharged substantially downwardly and provided no appreciable thrust power. By comparing at a given airplane velocity the engine-shaft horsepower for the two individual stack installations, with that for the collector-ring installation, an estimate is obtained of the exhaust-gas thrust horsepower for the individual stack installations. The apparent exhaust-gas thrust was calculated by means of the equation

$$\text{Thrust} = \frac{375\ \Delta\ \text{bhp}\ \eta}{V}$$

where

V is the airplane speed in miles per hour

and

η the propeller efficiency

Test data for a propeller similar in design to that used in the tests showed very little variation in efficiency over the test range, and a value of 0.85 taken from these data was used in computing the thrust.

RESULTS AND DISCUSSION

Effect of Discharge from Individual Exhaust Stacks on Airplane Speed

Figure 5 shows the data obtained on airplane speed V for various values of brake horsepower and altitude for the collector-ring installation, correlated by plotting

$$\sigma^{\frac{1}{2}}\ \text{bhp} \quad \text{against} \quad \left(\sigma^{\frac{1}{2}}\ V\right)^3$$

It is noted that a good correlation of the data at various altitudes is obtained. A slight trend with altitude is noted, the points for 20,000 feet being slightly higher than for 10,000 feet.

This difference may be the result of changes in propeller efficiency with the density of the air. The difference, however, is small and indicates that accurate correction of data at each pressure altitude for small variations in density from the standard may be made by means of equation (1).

Figure 6 shows the airplane speed obtained for the three exhaust conditions at 10,000, 17,000, and 20,000 feet altitude. A small correction for atmospheric density was applied in accordance with equation (1) to adjust the data to the standard density corresponding to each pressure altitude.

At full-throttle operation (approximately 44 in. Hg), the individual stacks provided 18-miles-per-hour increase in speed above the collector-ring installation at 20,000 feet, 15-miles-per-hour increase at 17,000 feet, and 13-miles-per-hour increase at 10,000 feet. The maximum speed obtained at full-open throttle with the smaller-stack-exit areas is slightly less than that with the larger-exit areas, but occurs at a reduced engine power. For example, figure 6 shows, for a constant manifold pressure of 44 inches Hg, that the engine power increases slightly in changing from the collector ring to the individual exhaust stacks with the 3.42 square-inch-exit areas, and decreases by about 8 percent when the stack-exit area is reduced to 1.77 square inches. For the same engine brake horsepower, the smaller exit stacks caused an increase of 5 miles per hour over the airplane velocity with the larger exit stacks. Thus an increase in efficiency was obtained with the 1.77 square-inch-exit stacks at the expense of a reduction in maximum engine power.

Because of the absence of data for intermediate nozzles, the points on the curves for the individual stacks and the stacks with nozzles for 44 inches manifold pressure, were joined with a straight line. Between the two exit areas, an optimum area exists, at which a maximum increase in efficiency or speed at a given engine power is obtained with no reduction in maximum power. It is noted that most of the gain in thrust has already been obtained with the individual stacks with 3.42-square-inch-exit area, and that the further gain to be expected from a reduction in exit area is small and would result in an increase in speed of less than 5 miles per hour.

Apparent Exhaust-Gas Thrust

Figure 7(a) shows the apparent exhaust-gas thrust of the individual exhaust stacks for the two exit areas plotted against brake horsepower. These curves were computed from the curves of figure 6. The values for the XP-41 in figure 7(a) can be taken as an indication only of the approximate magnitude of the thrust as differences in the drag and propeller efficiency of the various installations have not been eliminated. For example, the downward discharge of the exhaust gas from the exhaust collector may set up turbulence in the air stream and cause some drag, whereas this effect is not present in the case of the two individual stack installations. The flow of hot exhaust gas over the fuselage in the latter cases may change the fuselage drag. Although in all installations the exhaust exits were extended into the air stream to clear the airplane and reduce fire hazard, the different installations have a different external drag which is difficult to estimate. All these differences in drag appear in the values of the apparent exhaust-gas thrust.

An increase in apparent exhaust-gas thrust with altitude for a given engine power, as might be expected from theoretical consideration (reference 1), is noted. For a given power, the cylinder pressure at the time of exhaust-valve opening varies only slightly with altitude; however, the reduction in atmospheric pressure with altitude causes a higher expansion ratio for the gas discharge from the cylinder and a greater conversion of potential energy to kinetic energy in the gas stream.

Figure 7(b) shows the exhaust-gas thrust per slug per second of exhaust gas obtained in these tests compared with calculated values obtained from a theoretical analysis. The theoretical values represent the thrust obtained when the exhaust gas is discharged directly from the cylinder through a converging nozzle, and therefore do not contain the usual energy losses at the bends and area changes in the exhaust passage. The experimental values will probably approach the theoretical values as the losses in the exhaust port are reduced. Because of the belief that these losses in the present exhaust port are high, a larger difference between the theoretical and experimental thrust than is shown in figure 7(b) was expected. That a larger difference was not obtained, may be explained by the fact that the measured exhaust-thrust values contain the difference in drag of the two installations. It is of interest to note that the average apparent jet velocities are in the vicinity of the velocity of sound in exhaust gas at 2200° F absolute, which is approximately 2200 feet per second.

The increase in exhaust thrust with reduction in exhaust-exit area noted in figure 7(a), may be explained as follows:

The high pressure in the cylinder at the time the exhaust valves open, represents a large amount of potential energy. This potential energy is converted into kinetic and thermal energy as the gas discharges through the exhaust system to atmospheric pressure. The greater the efficiency of the discharge process, the larger the conversion of potential energy into kinetic energy, and the greater is the thrust of the exhaust gas. Considerable loss of kinetic energy occurs in the irregular exhaust passage between the exhaust valve and exhaust-valve seat, and in the exhaust port in the cylinder head. When the area at the exhaust-stack exit is reduced, the velocity through the exhaust valve and exhaust port is decreased with a reduction of the loss of kinetic energy at the valve. The available potential energy is more efficiently converted into velocity at the exhaust-stack exit because of its better shape as a nozzle as compared with the exhaust passage at the valve and an increased thrust is obtained.

As the stack-exit area is decreased, the time required for discharge of the cylinder to atmospheric pressure is increased. A point is reached, in reducing exhaust-stack-exit area, where sufficient time is not available for the drop of cylinder pressure to atmospheric and a large amount of residual gas is trapped in the cylinder by the closing of the exhaust valve with the result that a large drop in engine power for a given manifold pressure occurs.

As for a large part of the discharge, pressure ratios theoretically capable of producing supersonic velocities are involved, some improvement in thrust may result when a divergent passage is attached to the nozzle. No measurable improvement could be obtained in preliminary tests with divergent nozzles on a single-cylinder test engine. Further tests are planned.

Effect of Separate Exhaust Stacks on Engine Operation

Figure 8 shows the bmep plotted against manifold pressure for the various exhaust systems. The engine was equipped with a main blower and a two-speed auxiliary blower. The curves are broken where the blower condition is changed.

The values of the engine bmep with the individual stacks, exit area 3.42 square inches, are seen to be slightly higher than the values with the collector-ring installation for a given inlet manifold pressure. This indicates less resistance to discharge of the exhaust gas or a reduction in effective exhaust back pressure for the individual stacks as compared with the collector ring. This result may be expected as the pressure in the collector ring is somewhat greater than atmospheric. The marked reduction in bmep with the reduction in stack-exit area to 1.77 square inches is noted. It should be pointed out, however, that the engine installation was not designed with exhaust thrust in mind, and in order to avoid obstructions and find openings for the exhaust pipes, sharp bends in the pipes were required. The nozzles were welded to the exhaust stacks and a ridge of weld extended into the pipe. When these obstructions are removed and when the exhaust port in the cylinder is designed for better flow, it will be permissible to have more restriction in the area at the exit of the exhaust stacks than at present, with no loss in maximum engine power and a gain in thrust.

Figure 9 shows the head temperatures measured on the rear spark-plug gasket of no. 5 cylinder for the three exhaust conditions. The head temperatures were slightly lower for the individual stacks with 3.42-square-inch-exit areas than for the collector ring, again indicating slightly less exhaust back pressure. The reduction of the exit area to 1.77 square inches caused an appreciable increase in cylinder-head temperatures. All temperatures, however, were well below the permissible cruising temperature of 450° F.

From these tests it may be concluded that the exhaust-stack area of 3.42 square inches per cylinder was satisfactory in the present case, as it provided a large exhaust-gas thrust with no decrease in maximum engine power or increase in cylinder temperatures. The exit area of 1.77 square inches cannot be considered as satisfactory for the present application as it reduced the maximum engine power and maximum flight speed with respect to that obtained with the 3.42-square-inch exits, and caused considerable increase in cylinder temperature. The efficiency was greater for the 1.77-square-inch-exit area than for the 3.42-square-inch-exit area, as a higher airplane velocity was obtained for a given brake horsepower. Possibly some intermediate exit area would give the maximum performance.

CO Contamination of the Cockpit and Exhaust-Flame Visibility

Tests were made with the individual stack installation, exit area 3.42 square inches, at a number of flight conditions with a CO meter in the cockpit. The following concentrations of CO were measured.

1. High-speed level flight, 30-inch Hg manifold pressure, 2400 rpm, cowl flaps one-third open at 10,000 foot altitude.

Lower right side of cockpit - 0.005 percent CO

Lower left side of cockpit - 0.015 percent CO

At the pilot's face - 0.0060 - 0.0075 percent CO

2. In climb at an indicated air speed of 150 miles per hour, 30-inch Hg manifold pressure, 2400 rpm, cowl flaps wide open.

Lower right side of cockpit - 0.0060 percent CO

Lower left side of cockpit - 0.0175 percent CO

At the pilot's face - 0.02 percent CO

3. In a glide with the cockpit cover open, 10-inch Hg manifold pressure.

At the pilot's face - 0.0050 to 0.0060 percent CO

Grow (reference 2) has recommended that 0.005 percent CO be specified as the maximum allowable concentration. Although all the measured CO concentrations exceeded the value of 0.005 percent, it is reasonable to expect that with better insulation against exhaust gas and by ventilation of the cockpit with uncontaminated air, this condition can be remedied.

No determination was made of the CO concentrations with the exhaust collector-ring installation, so that no conclusion can be given with regard to whether contamination of the cockpit was worse with individual stacks.

The intensity of the exhaust noise with individual stacks seemed only slightly greater than that of the collector ring but the discharges were sharper and more annoying. The electrical interference on the radio was also greater with the individual stacks than with the collector ring. The cause of this interference has not been determined.

The tests herein described were made with the individual stacks extending into the air stream and the exhaust directed at an angle of 30° relative to the fuselage axis. (See figs. 2 and 4.) With this arrangement, it is believed that no excessive heating of the fuselage occurred. The exhaust stacks were later cut back into the cowling so that they did not extend into the air stream, and a ground test was made with several temperature-sensitive paints applied to the fuselage immediately behind the exhaust-stack exit. The tests indicated that immediately behind the exhaust stacks the temperature on portions of the stainless-steel bulkhead on the nose of the fuselage was above 338° F. Portions of the duralumin parts of the fuselage behind several of the stacks were also above 338° F; whereas, behind the remainder, temperatures less than 338° F were attained. For these more streamlined installations, tests should be made for excessive heating of the fuselage and stainless-steel shields applied where necessary. Airplane velocities with this modification have not been determined as yet, although further tests are planned.

Figure 10 shows a photograph taken at night with the engine operating at 30 inches Hg inlet-manifold pressure and the mixture control set in the lean cruising position. It was found necessary to ignite a photo-flash bulb to obtain the outline of the airplane in the picture. At full rich mixture the exhaust discharge was practically invisible to the eye. As the mixture was leaned the discharge brightened and turned to a blue color. At no time was the light very intense. The flame extended for a distance of approximately 1 foot from the exhaust stack.

Discussion of Separate Stack Installation

In the present installation, because of the lack of space, the exhaust of four of the cylinders was connected in pairs. The thrust of these cylinders was probably considerably less than that of the cylinders provided with separate exhaust stacks because of the loss of energy at the bend and at the sudden area enlargement at the junction of the branched stacks. Installations of this type should be avoided. If unavoidable, only cylinders with nonoverlapping exhaust-valve timing should be connected together.

The following differences between a separate exhaust-stack installation and a collector-ring installation with regard to exhaust thrust should be appreciated.

It is recalled that when a pressure ratio of more than approximately 2:1 exists across a simple orifice in the cylinder wall, the velocity of discharge of the exhaust gas through the orifice equals the velocity of sound. In addition, the pressure at the orifice exit is greater than atmospheric and is approximately one-half the pressure in the cylinder. Thrust is provided by the excess pressure above atmospheric and by the momentum of the gas at the nozzle exit. If a compound nozzle is used, comprising a convergent section followed by a properly designed divergent section, the pressure at the exit will be atmospheric and the discharge velocity will be greater than that of sound. The thrust obtained in this case will be greater than that obtained with the simple nozzle. As the pressure in the cylinder varies, however, the exit area of the divergent section must also be variable to obtain the maximum thrust.

The exhaust passage at the conventional exhaust valve may be pictured as a simple nozzle. At high bmep the pressure in the cylinder at the time the exhaust valve opens is greater than 100 pounds per square inch. With an atmospheric pressure of 7 pounds per square inch (approximately 20,000 feet altitude), the velocity through the valve will be of the order of that of sound during the time of reduction of the pressure from above 100 pounds per square inch to about 14 pounds per square inch. Thus the major portion of the exhaust gas is discharged through the valve with a velocity of approximately 2200 feet per second (the velocity of sound in exhaust gas at 2200° F absolute). An excess pressure is developed at the exit which is converted into increased velocity in accordance with the law that force is equal to rate of change in momentum. In the usual collector-ring installation, the largest part of the velocity generated by the cylinder pressure is lost in the sharp bends and sudden enlargements in pipe area inherent in exhaust systems of this type. To regenerate a velocity equal to that of sound, for example, at the exit of the collector ring, it would be necessary to install a nozzle providing a pressure in the collector ring twice atmospheric with a very appreciable loss in engine power. The impossibility of again providing the thrust from the exit of a collector ring which was provided by the cylinder pressure without considerable loss in engine power, is apparent. The inadvisability with regard to exhaust thrust of connecting a number of cylinders to a common manifold, is also apparent.

A nozzle on the end of an individual exhaust stack differs from a nozzle on the end of a collector ring in its effect on engine power. In the former case, although the nozzle restricts the flow, the cylinder pressure can discharge to atmospheric pressure if sufficient time is available. A nozzle on a collector-ring exit increases the velocity of discharge at the expense of a constant increased pressure in the collector ring, and the cylinder pressure can discharge only to collector-ring pressure.

The guiding principle in obtaining exhaust-gas thrust with maximum efficiency is to convert as much as possible of the waste pressure in the cylinder to velocity of discharge. To this end, the exhaust system should be designed with as few bends and sudden area enlargements as possible.

Necessary bends should be gradual and followed by a straight portion of pipe extending rearward as nearly parallel to the direction of flight as possible.

CONCLUSIONS

The following conclusions may be drawn for the airplane used in these tests:

(1) Increases in maximum speed of 13, 15, and 18 miles per hour at 10,000, 17,000, and 20,000 feet altitude, respectively, were obtained with individual stacks for each cylinder discharging rearwardly as compared with the collector-ring installation.

(2) Of the two sets of stacks tested, the stacks having exit areas of 3.42 square inches per cylinder, were better than the stacks having exit areas of 1.77 square inches, in that the maximum speeds were slightly higher and the cylinder temperatures were considerably lower with the larger exit areas. The cylinder temperatures with the stacks having the larger exit areas were slightly less than the temperatures for the collector-ring installation at the same engine power.

(3) For an inlet manifold pressure of 44 inches Hg at 20,000 feet altitude (160 lb per sq in. bmep) at 2550 rpm, no loss in power was experienced with the stacks having exit areas of 3.42 square inches per cylinder. With half this exit area for 10 of the 14 cylinders, approximately 8-percent loss in power was experienced at the same engine speed and inlet manifold pressure.

(4) Exhaust visibility was quite low, maximum visibility occurring in the lean-mixture range. In the rich-mixture range the exhaust flame was practically invisible.

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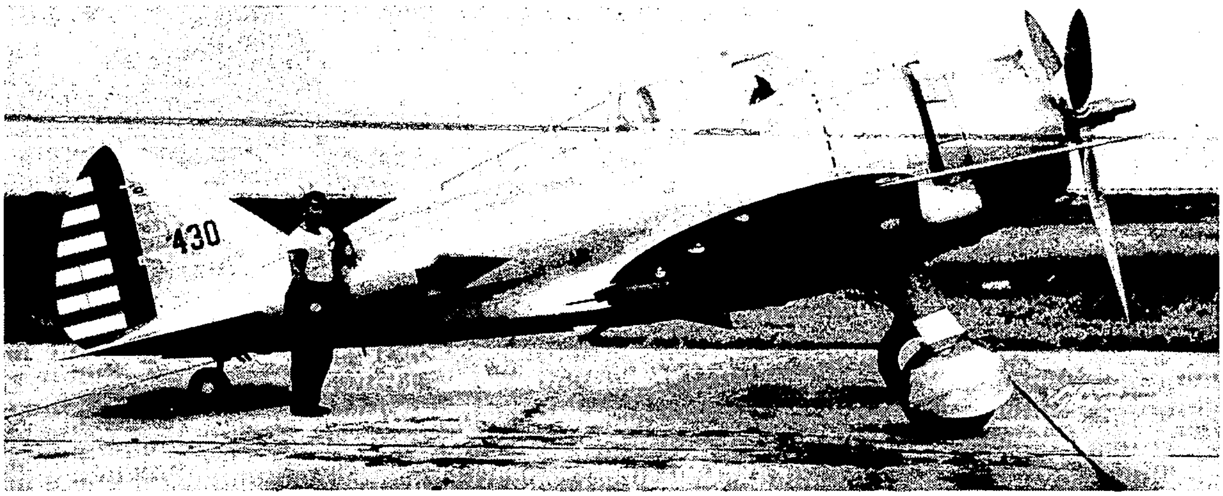


Figure 1a.- The XP-41 airplane

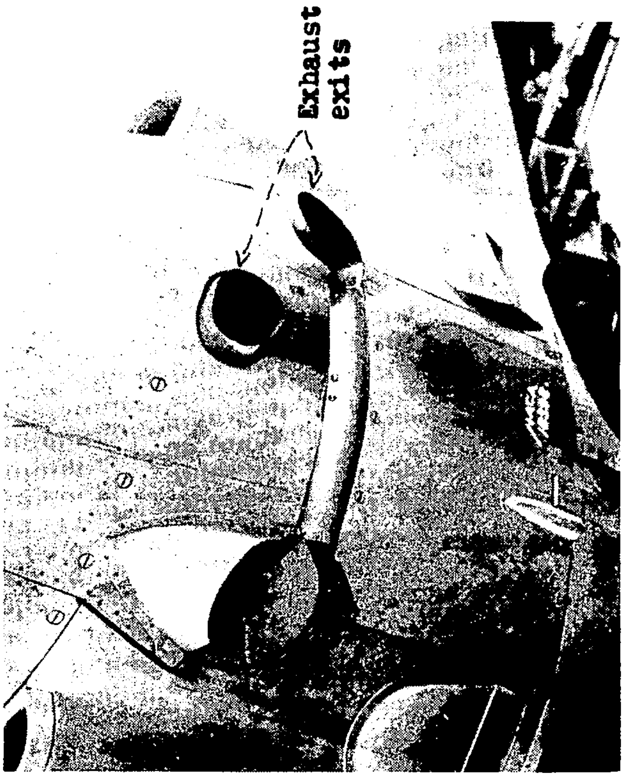


Figure 1b.- Detail of exits of the exhaust collector-ring installation.

Figure 1a,b.- The XP-41 airplane with collector-ring installation.

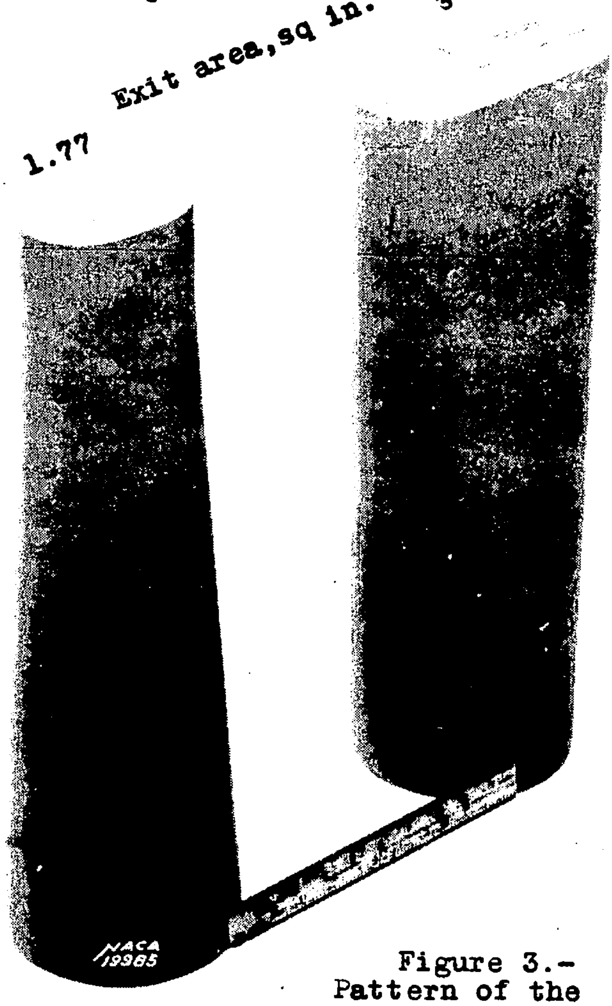
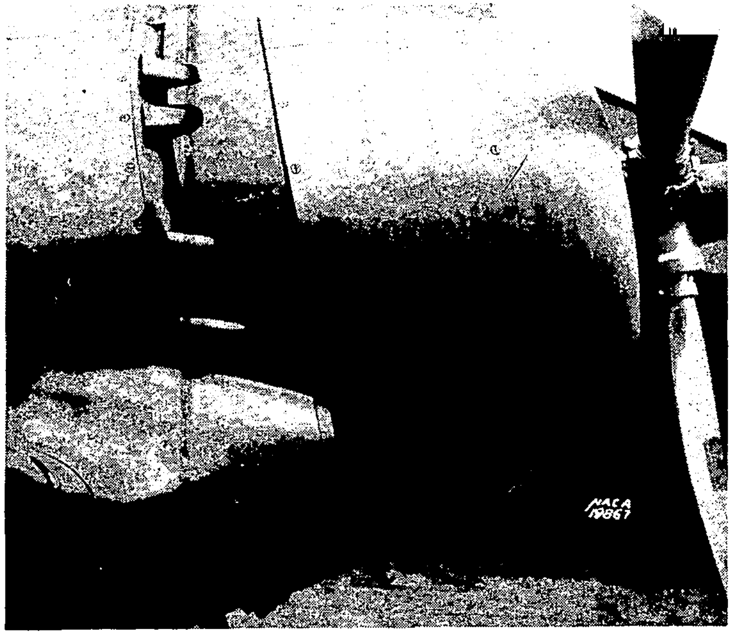
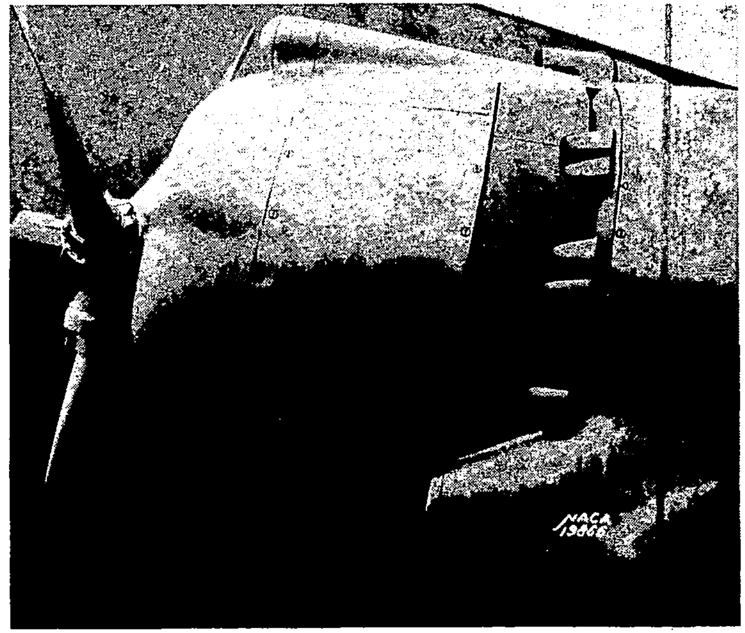


Figure 3.- Pattern of the exit of the individual exhaust stacks-





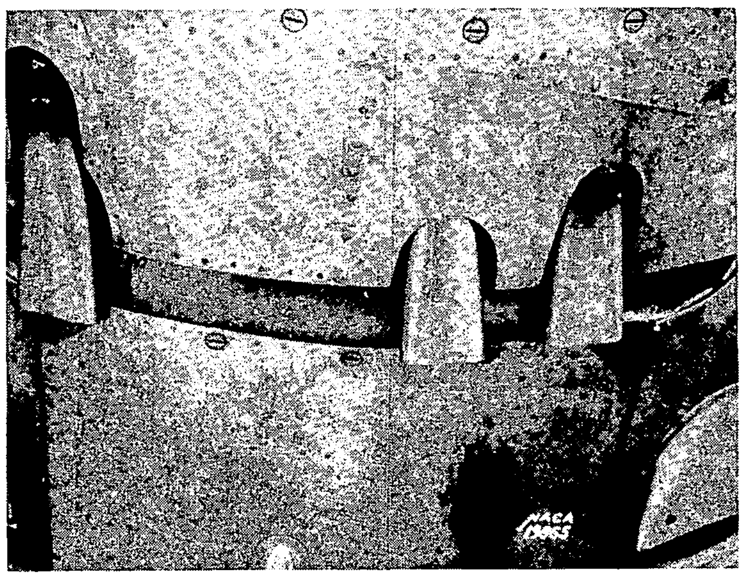
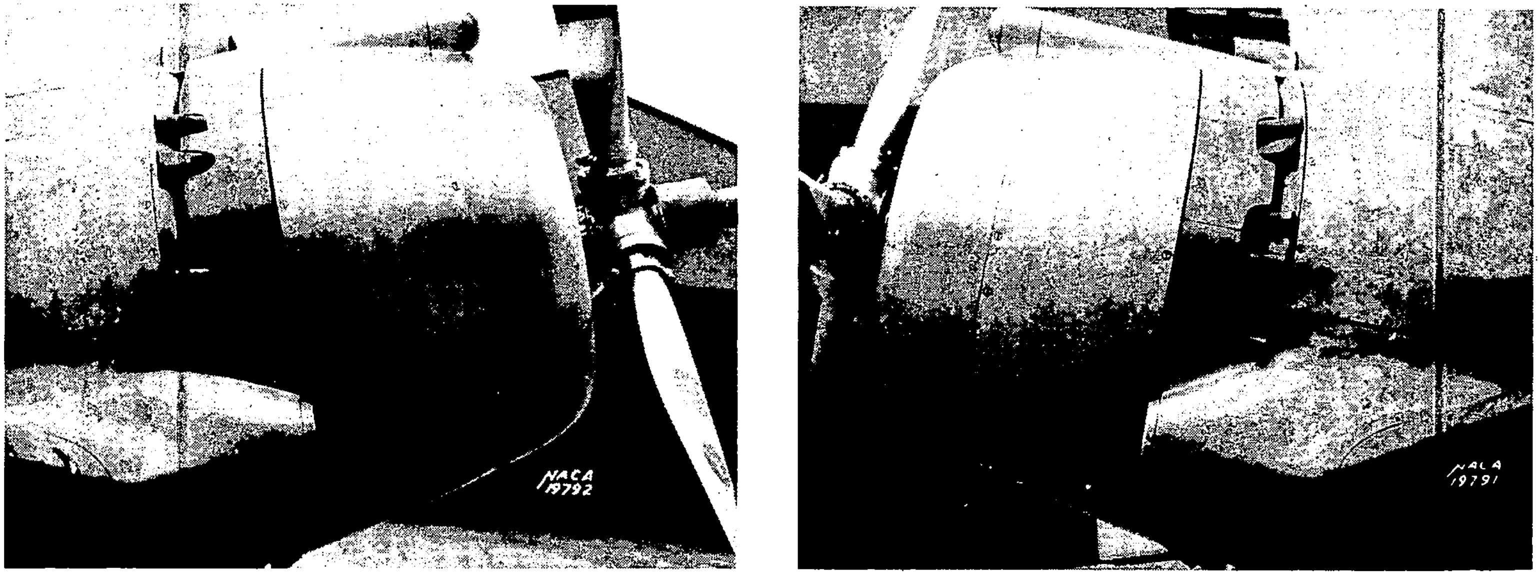


Figure 2.- Individual exhaust stacks with exit area of 3.42 square inches installed on the XP-41 airplane



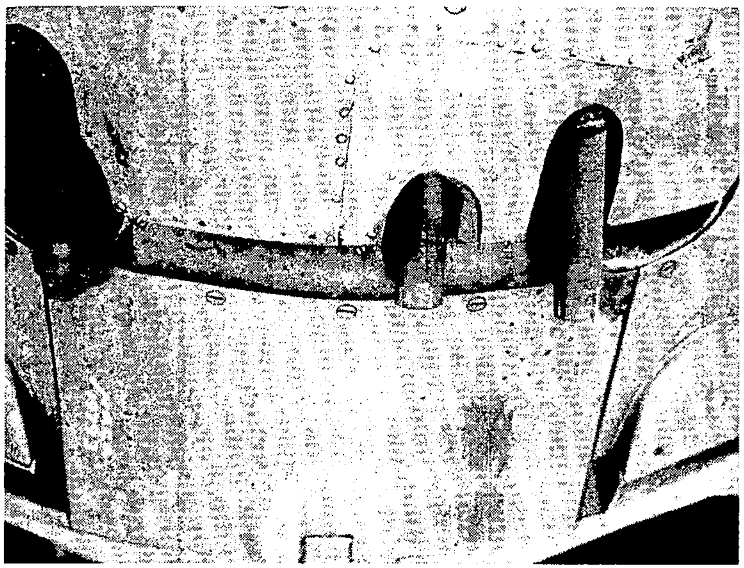


Figure 4.- Individual exhaust stacks with exit area of 1.77 square inches installed on the XP-41 airplane.

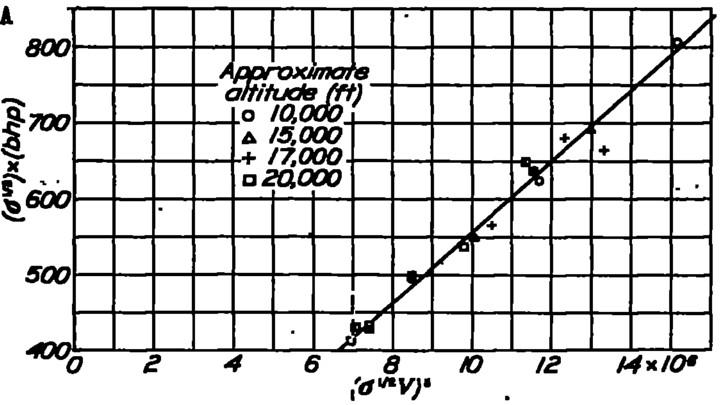


Figure 5.- Power-speed characteristics of the XP-41 airplane with exhaust collector installed

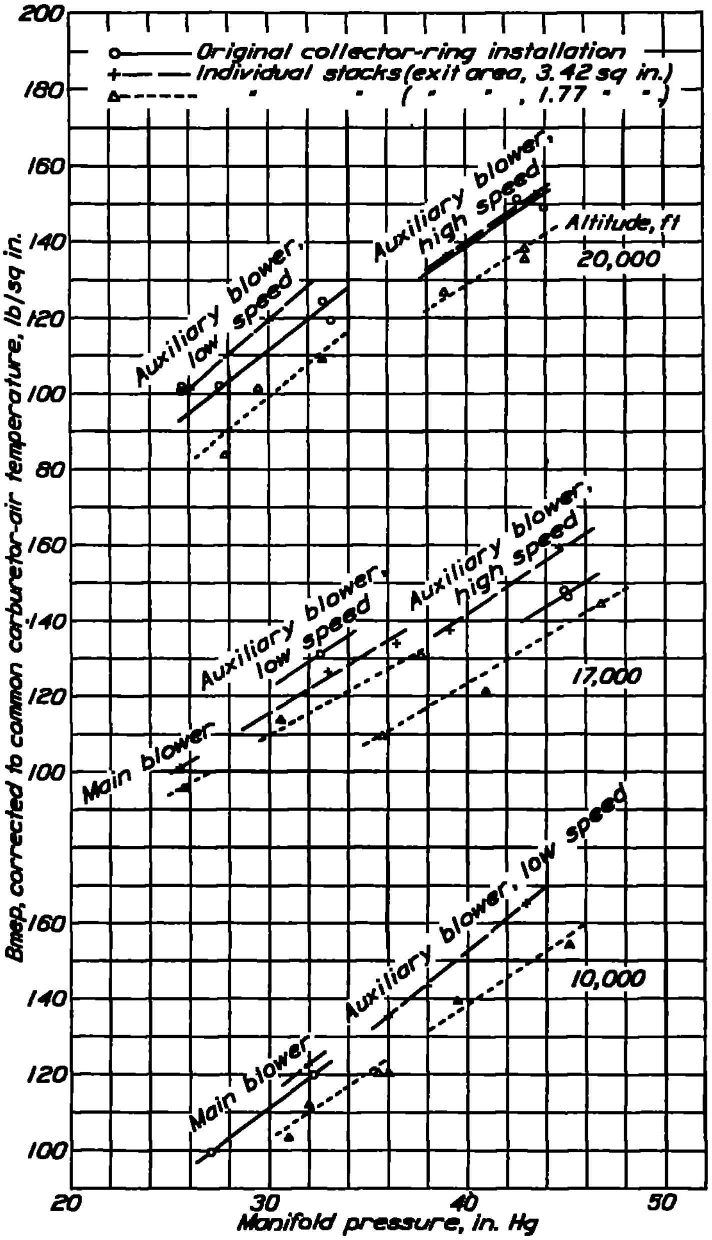


Figure 6.- Effect of exhaust restriction on power.

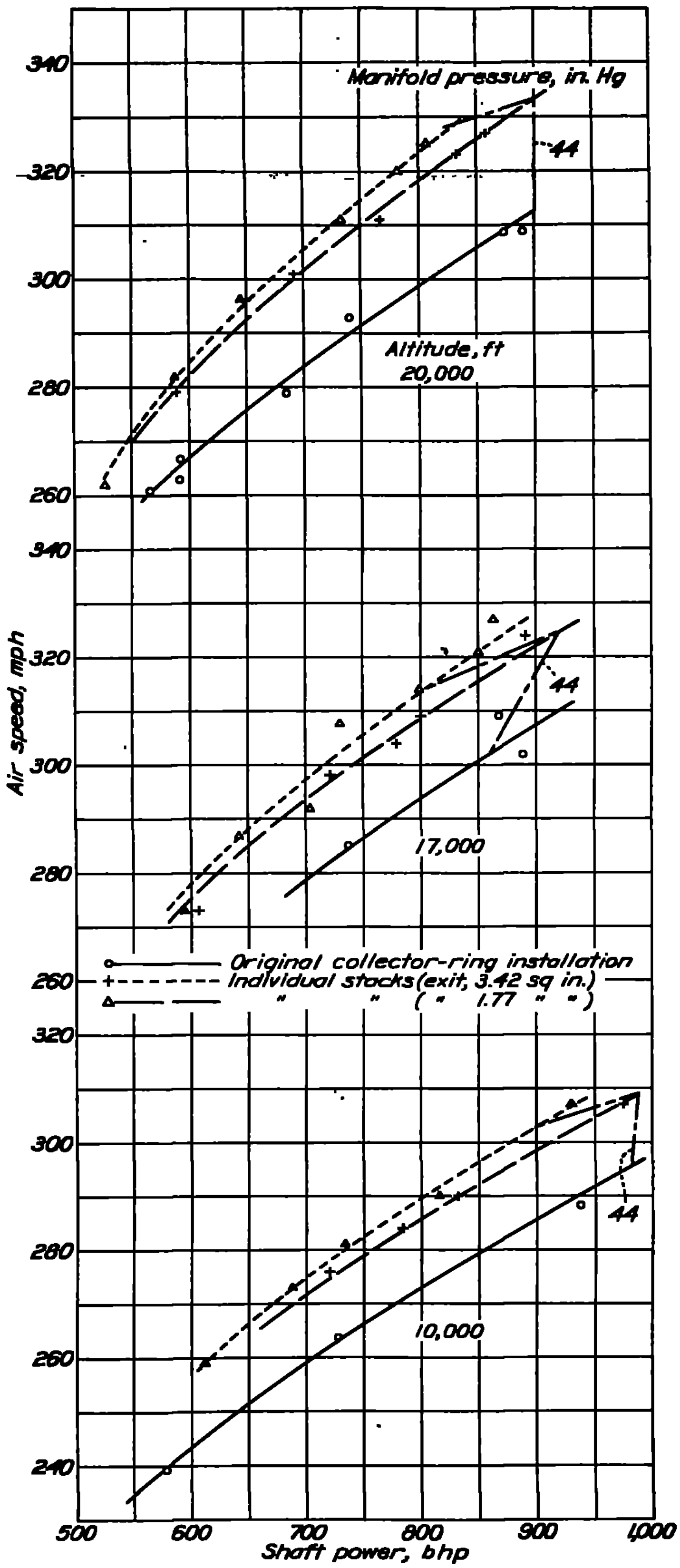
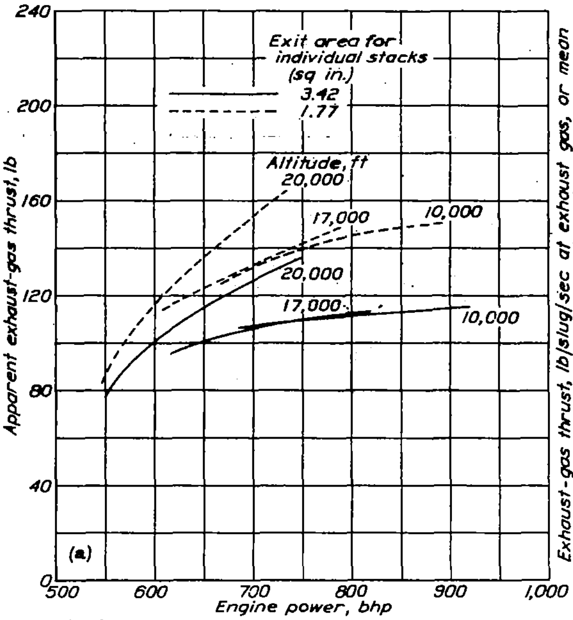
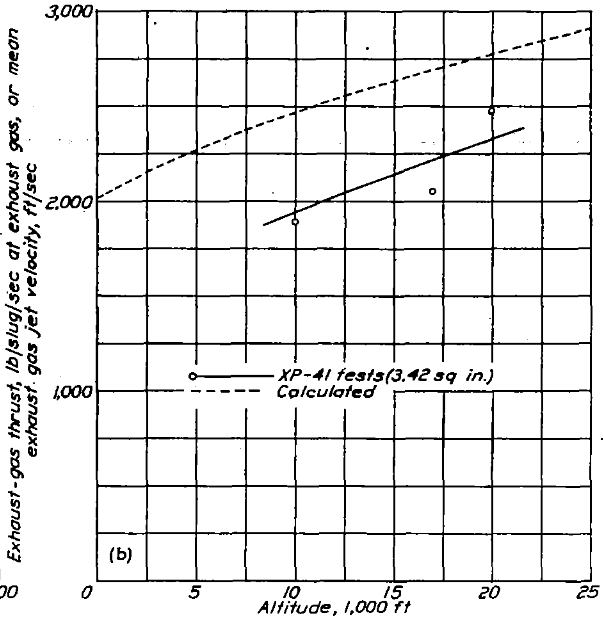


Figure 6.- Power-speed characteristics of the XP-41 airplane with various exhaust systems.



(a) Variation with engine power.



(b) Compared with calculated thrust (inlet manifold pressure, 34 in. of mercury).

Figure 7,a and b.- Apparent exhaust-gas thrust for individual exhaust stacks.

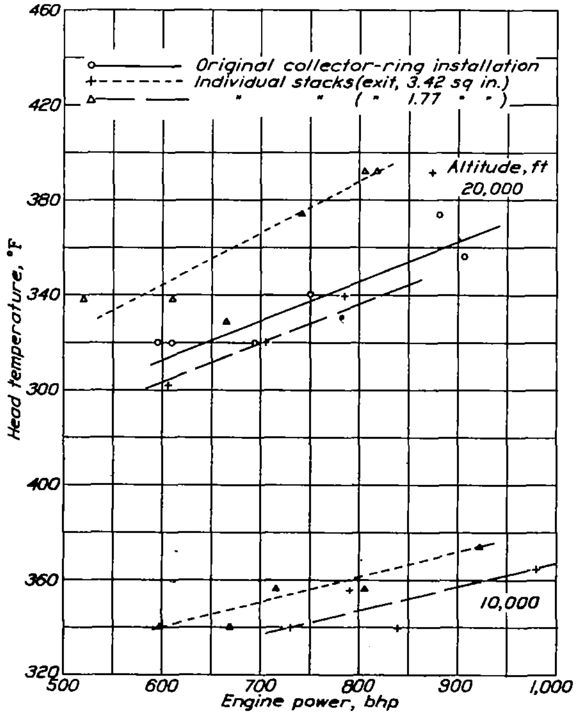


Figure 9.- Effect of exhaust restriction on engine temperature.

Figure 10.- Night visibility of exhaust flames with individual exhaust stacks.

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ABSTRACT:

Experiments were conducted on the XP-41 pursuit airplane with Pratt and Whitney R1830 engine to determine the effect of exhaust-stack installations on flight speed and cylinder temperature. Two types of installation which had exit areas of 3.42 and 1.77 sq in. respectively were used. Results showed increases in maximum speed up to 18 mph at 20,000 altitude. Larger exhaust stack was better than the smaller in that higher speed and lower cylinder temperatures were obtained.

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