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RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

ACCELERATION CHARACTERISTICS OF R-3350 ENGINE EQUIPPED WITH NACA INJECTION IMPELLER

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Qualitative investigations have shown that use of the NACA injection impeller with the R-3350 engine increases the inertia of the fuel-injection system and, when the standard fuel-metering system is used, this increase in inertia results in poor engine acceleration characteristics. This investigation was therefore undertaken to determine whether satisfactory acceleration characteristics of the engine equipped with the injection impeller could be obtained by simple modifications to the fuel-metering system. The engine was operated with two types of carburetor; namely, a hydraulic-metering carburetor incorporating a vacuum-operated accelerating pump and a direct-metering carburetor having a throttle-actuated accelerating pump.

The vacuum-operated accelerating pump of the hydraulic-metering carburetor was modified to produce satisfactory accelerations by supplementing the standard air chamber with an additional 75-cubic-centimeter air chamber and by decreasing the strength of the primary spring.

The throttle-actuated accelerating pump of the direct-metering carburetor was modified to produce satisfactory accelerations by replacing the standard 0.028-inch-diameter bleed in the load-compensator balance line with a smaller bleed of 0.0225-inch diameter.

The results of this investigation indicated that both carburetors can be easily modified to produce satisfactory acceleration characteristics of the engine and no definite choice between the types of carburetor and accelerating pump can be made. Use of the direct-metering carburetor, however, probably resulted in better fuel

distribution to the cylinders during the acceleration period and reduced the backfire hazard because all the fuel is introduced through the injection impeller.

INTRODUCTION

At the request of the Air Materiel Command, Army Air Forces, a general investigation of methods for improving the cooling characteristics of the R-3350 engine has been conducted at the NACA Cleveland laboratory. Use of the NACA injection impeller improves the mixture distribution and consequently the temperature distribution of the engine (reference 1).

In the investigation reported in reference 1, the injection impeller, when used with the standard fuel-metering system, gave poor engine acceleration characteristics, but satisfactory acceleration was obtained by doubling the volume of the accelerating-pump air chamber of the Ceco 58 CPB-2 carburetor that was used for that investigation. Because the acceleration tests of reference 1 were only qualitative, more detailed information was obtained on accelerating-pump requirements and on methods of injecting the fuel for acceleration for the engine equipped with the injection impeller.

When the injection impeller and a Ceco 58 CPB-2 or Ceco 58 CPB-4 carburetor, which are of the hydraulic-metering type and have a vacuum-operated accelerating pump, are used during steady engine operation, the fuel is injected through the impeller; whereas the additional fuel for acceleration is injected at the carburetor bottom deck. This spray is not conducive to rapid evaporation of the fuel and the increase in air pressure at this point, which results from opening the throttle, further hinders fuel evaporation. Appreciable amounts of fuel probably wet the walls of the combustion-air passage before complete evaporation takes place and this wetting introduces an appreciable time interval before additional fuel reaches the cylinders. This time lag adversely affects the acceleration characteristics of the engine. When the standard nozzle bar is used, this time interval is not so pronounced because the combustion-air passage downstream of the carburetor is already filled with a fuel-air mixture and the surrounding walls have been wetted with fuel.

When the engine uses the injection impeller and the Ceco 58 CPB-3X carburetor, which is of the direct metering type and has a throttle-actuated accelerating pump, both the fuel for steady engine operation and the additional fuel for acceleration are injected through the impeller. The resistance to fuel flow through the fuel-transfer lines and the nozzle ring of the injection impeller is greater than that for nozzle-bar injection. This increased resistance tends to increase the inherent lag in the fuel-metering system and adversely affects the acceleration characteristics of the engine.

The results of an investigation of the accelerating characteristics of a standard R-3350-23 engine and of the R-3350-23 engine incorporating an injection impeller with two different types of carburetor are presented. The standard engine has a Ceco 58 CPB-4 hydraulic-metering carburetor and the fuel is injected through a standard nozzle bar. This fuel-metering system, configuration A, was investigated to supply a criterion for evaluating the acceleration characteristics of the engine with the injection impeller. Configuration B consisted of an R-3350-23 engine with an injection impeller and a Ceco 58 CPB-4 carburetor; configuration C consisted of the same engine and impeller with a Ceco 58 CPB-3X direct-metering carburetor. Modifications were made to the accelerating pumps of the carburetors of configurations B and C until the engine exhibited acceleration characteristics comparable with those of configuration A.

Accelerations from initial engine speeds between 600 and 1800 rpm were investigated; the time required to open the throttle to the wide-open position was varied from 2/3 to 12 seconds for each initial engine speed. The results are presented as curves of engine speed against time.

FUEL-METERING AND INJECTION SYSTEMS

Configuration A. - In this configuration a standard fuel-injection and metering system was used. The fuel was injected at the carburetor bottom deck through a standard nozzle bar and the fuel was metered by a standard Ceco 58 CPB-4 carburetor. This carburetor is of the hydraulic-metering type and has a vacuum-operated accelerating pump. A schematic diagram of the accelerating pump is shown in figure 1. The accelerating pump is operated by a differential pressure across the air diaphragm. As the throttles are opened, the air pressure downstream of the throttles is increased, which causes a pressure rise in the accelerating-pump pressure passage. The flow resistance of the fixed bleed between the pressure passage and the air chamber causes a pressure differential across the air diaphragm for an appreciable length of time. When the pressure differential across the diaphragm is great enough to overcome the force of the primary spring, the pump valve opens and the fuel at fuel-pump pressure sprays into the combustion air from the pump nozzle immediately upstream of the throttles. The secondary spring does not become effective until the valve has opened slightly. For a given set of primary and secondary springs, the magnitude of the persure differential across the air diaphragm determines the length of travel of the valve and consequently the fuel flow. The duration of the fuel discharge is controlled by the duration of the pressure differential across the air diaphragm, which depends principally upon the bleed size and air-chamber volume. With this type of accelerating pump, the extra fuel supplied during the acceleration period completely bypasses the carburetor fuel-metering system and enters the combustion air independently of the fuel supplied for normal engine operation.

Configuration B. - This configuration of the fuel-injection and fuel-metering system consisted of an NACA injection impeller (fig. 2) and a Ceco 58 CPB-4 carburetor. A complete description of this impeller and the fuel-transfer system is given in reference 1. As in configuration A, the additional fuel supplied during the acceleration period was introduced into the combustion air immediately upstream of the carburetor throttles. The fuel for normal engine operation was injected through the injection impeller.

The modifications to this configuration to improve the acceleration characteristics consisted in decreasing the strength of the primary spring of the carburetor accelerating pump and of increasing the volume of the air chamber. The standard bleed between the pressure passage and the air chamber is so small that any reduction in size would induce clogging.

Configuration C. - This configuration incorporated the NACA injection impeller and a direct-metering Ceco 58 CPB-3X carburetor, which has a throttle-actuated accelerating pump. A schematic diagram of the component parts of the accelerating-pump system is shown in figure 3. As the throttle is opened, the accelerating-pump piston, which is actuated by the throttle linkage, displaces a small amount of fuel and thus increases the fuel pressure in the load-compensator balance line. This increase in pressure is transmitted to the load-compensator chamber of the pressure regulator and results in an unbalanced force upon the metering diaphragms. This unbalanced force increases the opening of the pressure-regulator valve and permits more fuel to flow through the pressure regulator to the engine. The amount and the duration of the unbalance resulting from the movement of the accelerating-pump piston is controlled primarily by fixed bleed A (fig. 3).

With this type of carburetor, the fuel required for normal engine operation and the additional fuel supplied during the acceleration period are discharged through the same system. Modifications to this configuration consisted in reducing the bleed diameter, which resulted in a greater unbalance of the pressure regulator for a longer period of time and in a greater quantity of fuel for the acceleration period.

APPARATUS

Setup. - This investigation was conducted on an R-3350-23 engine that was fitted with a ring cowling and installed in a test cell, as shown in figure 4. The engine power was absorbed by a four-blade propeller, 16 feet and 7 inches in diameter. Cooling air was drawn across the engine by a controllable suction system. The combustion-air system automatically maintained the carburetor-deck temperature at 100° ±5° F. Each cylinder exhausted directly to the atmosphere through individual stub stacks.

Instrumentation. - The instruments used to determine the acceleration performance of the engine were mounted on a panel in order that all pertinent readings could be simultaneously photographed by a motion-picture camera. Values of engine speed and time were indicated by a chronometric tachometer. The throttle angle was determined by an electric position indicator that was calibrated to indicate the throttle angle directly in degrees. Backfiring of the engine was audibly detected by an observer in the control room who operated a manual microswitch controlling the backfire-indicating light, which indicated backfire on the instrument panel.

Throttle and mixture were manually controlled by the engine operator. An additional chronometric tachometer mounted in front of the engine operator was wired in parallel and syncronized with the tachometer used to determine the acceleration characteristics of the engine. With this arrangement, the engine operator could correctly regulate the rate of throttle opening by observing the electric timer of the chronometric tachometer. Other engine controls and instrumentation were of conventional design and operation.

OPERATING PROCEDURE

The acceleration characteristics of the standard R-3350 engine (configuration A) were determined to form a basis for evaluating the acceleration characteristics of this engine with the injection impeller and a Ceco 58 CPB-4 or Ceco 58 CPB-3X carburetor. Before the engine acceleration was investigated, both carburetors were tested in an air box and adjusted to meter fuel within the limits specified by the engine manufacturer. The accelerating pumps were also tested and adjusted to meter fuel in the proper amounts for acceleration. Investigations of configuration A were made from initial engine speeds of 600, 900, 1200, 1500, and 1800 rpm. At each initial engine speed, the throttle was smoothly opened to the full-open position in times of 2/3, 2, 4, and 6 seconds.

In the investigation of configuration B, the acceleration characteristics with each modification to the accelerating pump of the carburetor were evaluated by visual observation. If the modification seemed satisfactory, additional runs were made during which motion pictures were taken of the acceleration instrument panel. The investigation of this configuration covered the same initial speeds and rates of throttle opening as for configuration A. In addition, runs were made for a throttle-opening time of 12 seconds from those initial speeds that exhibited hesitation or backfiring.

The investigation of configuration C was similar to that of configuration B and covered the same range of conditions. These studies thus covered a range of accelerations from "snap" throttle opening (2/3 sec) to extremely slow throttle opening (12 sec) from low idling speed (600 rpm) to engine speed used for landing approaches (1800 rpm).

Representative curves showing throttle position against time for three different rates of throttle opening are shown in figure 5. The variations of the actual throttle angles from those for a uniform rate of throttle opening are very small. The acceleration characteristics obtained therefore represent a uniform rate of throttle opening.

For all operation, the propeller was set in low pitch (21°) and the propeller governor was adjusted to maintain a maximum engine speed of 2400 rpm. With these propeller and governor settings, the propeller remained in fixed pitch and the governor was inoperative until the engine speed approached 2400 rpm. This arrangement resulted in a relation of engine speed and power that closely followed the propeller-load curve for the engine up to a speed of about 2400 rpm. Throughout this investigation, AN-F-28 fuel was used.

RESULTS AND DISCUSSION

Standard Engine

The results with the standard R-3350 engine (configuration A) are shown in figure 6 as curves of engine speed against time. At snap throttle opening (2/3 sec from idling to wide-open throttle position) the engine backfired and the engine speed decreased when the acceleration began from engine speeds between 600 and 1200 rpm. The decrease in engine speed after each backfire was about 90 rpm. The total time required to change the engine speed from 600 to 2400 rpm was approximately four times that obtained by the manufacturer. The comparatively long period of time required for the present tests is attributed to the fact that the engine pistons not only had to supply the torque for accelerating the engine and propeller but also had to supply the torque necessary to overcome the large aerodynamic forces of the propeller set in low pitch. When the time for opening the throttle was increased to 2 seconds, backfiring occurred only when the acceleration began at an engine speed of 600 rpm. The loss in engine speed after backfiring was about 130 rpm. For other combinations of rate of throttle opening and initial engine speed, the operational characteristics during acceleration were excellent. Accelerations from engine speeds of 1200 rpm or less at relatively rapid rates of throttle opening are quite severe and are unlikely to be encountered in normal engine operation. Inasmuch as this engine-carburetor combination is used in service, the acceleration characteristics were assumed to be satisfactory for service use and were used as a basis of evaluating the acceleration performance of the engine with the injection impeller.

Engine with NACA Injection Impeller

and Ceco 58 CPB-4 Carburetor

The acceleration characteristics of the engine equipped with the NACA injection impeller and a standard Ceco 58 CPB-4 hydraulic-metering carburetor (configuration B) were poor. Visual observation showed that all accelerations from engine speeds less than 1800 rpm at rates of throttle opening faster than 12 seconds were unsatisfactory. Considerable hesitation of the engine speed usually followed by backfiring and loss of engine speed, which resulted from a definite leaning of the fuel-air mixture as the throttle was opened, was observed.

The vacuum-operated accelerating pump of this carburetor was modified in several steps to determine an approximately optimum modification for satisfactory acceleration of the engine incorporating the injection impeller. First, the air chamber was enlarged to increase the duration of accelerating-fuel delivery and, second, the primary-spring tension was decreased to obtain the necessary initial rate of fuel flow. The third modification consisted of a combination of an increased air-chamber capacity and a decreased primary-spring tension.

The volume of the air chamber was increased about 120 percent by the addition of a 75-cubic-centimeter well (fig. 7). An increase in the volume of the air chamber increases the time required for the pressure in the chamber to become equal to the pressure downstream of the throttle when the throttle is opened. The increase results in increasing the length of time during which fuel is injected by the accelerating pump. Visual observation of the acceleration characteristics with this modification indicated that the duration of the accelerating fuel discharge was approximately correct but that the initial rate of fuel discharge was inadequate.

The additional air chamber was then removed and the primary-spring tension was altered to determine the requirements for initial rate of fuel discharge. Attempts to shim the spring housing gave insufficient change in spring tension to affect the acceleration characteristics of the engine. A primary spring with a working length of 1.06 inches under a 2-pound load was then installed in place of the standard spring, which has the same length under a load of 2 pounds, 6 ounces. This modification produced good acceleration characteristics at the initial part of the acceleration period, but the duration of the accelerating fuel discharge was not adequate to provide smooth acceleration to full engine speed.

The results with the combination of a weaker primary spring and a 75-cubic-centimeter increase in air-chamber volume were photographed. The curves of engine speed against time (fig. 8) indicate adequate initial accelerating fuel discharge and adequate duration of accelerating fuel discharge. No backfiring was encountered when the throttle was opened in 2/3 or 2 seconds. In this respect the acceleration characteristics with the modified carburetor and injection impeller were better than with the standard carburetor and the nozzle bar. When the throttle was opened in 4 and 6 seconds from an engine speed of 600 rpm, the engine hesitated for about 3 seconds before starting continuous acceleration. When the acceleration began at an engine speed of 900 rpm and the throttle was opened in 6 seconds, the engine accelerated satisfactorily up to an engine speed of 1460 rpm, then backfired with a loss in engine speed of 150 rpm before final acceleration began.

When the throttle was opened slowly (12 sec to reach the wide-open position) the acceleration characteristics were poor from initial engine speeds of 600, 900, and 1200 rpm. When the acceleration started from an engine speed of 600 rpm, the engine speed hesitated between 600 and 700 rpm for about 5 seconds before accelerating. Accelerations from these low initial speeds is a more severe requirement than service conditions impose and is therefore not considered critical. Black smoke from the engine exhaust indicated that this hesitation was caused by an over-rich fuel-air mixture. When the acceleration began from an engine speed of 900 rpm, considerable backfiring and fluctuation in engine speed occurred for almost 7 seconds; then acceleration was smooth and rapid. From an initial engine speed of 1200 rpm, the engine accelerated to about 1400 rpm, backfired and lost engine speed, and then accelerated satisfactorily. Accelerations from engine speeds of 1500 rpm and above were satisfactory.

The quantities of fuel metered by the modified pump are compared with the values recommended by the carburetor manufacturer for the standard pump in figure 9. The modified pump delivers two and one-half to three times as much fuel as the standard pump.

Tests were also made with the 75-cubic-centimeter air chamber replaced with one having a volume of 200 cubic centimeters, but this modification showed that further increase in air-chamber volume gave no improvement in acceleration characteristics over those obtained with the addition of 75 cubic centimeters to the air-chamber volume.

Engine with NACA Injection Impeller

and Ceco 58 CPB-3X Carburetor

Results of acceleration tests of the engine with the NACA injection impeller and a standard Ceco 58 CPB-3X direct-metering carburetor (configuration C) are presented in figure 10. Because the Ceco 58 CPB-3X carburetor discharges the fuel for normal engine operation and the additional fuel required for acceleration through the same system, this carburetor was expected to provide better acceleration characteristics when used with the injection impeller than did the Ceco 58 CPB-4 carburetor. In general, however, the acceleration characteristics were unsatisfactory when acceleration started at engine speeds below 1500 rpm at rates of throttle opening between 2/3 and 6 seconds. Considerable backfiring and loss of engine speed resulted from excessively lean mixtures. In most instances of backfiring and loss of engine speed, steady acceleration did not take place for 2 to 4 seconds. At a slow rate of throttle opening (12 sec), the engine speed hesitated for about 4 seconds before beginning to accelerate from 600 rpm. All other accelerations were satisfactory at this rate of throttle opening.

The bleed in the load-compensator balance line (bleed A, fig. 4) was decreased in size to provide a higher initial rate of fuel discharge that would eliminate the lean operation during the early part of the acceleration period. The first modification was to replace the standard 0.028-inch-diameter bleed with a bleed of 0.020-inch diameter. This modification caused appreciable flooding of the engine at all fast rates of throttle opening. The excessive leanness resulting in backfiring was eliminated at the slower rates of throttle opening.

A bleed of 0.0225-inch diameter was then installed in the load-compensator balance line and the results of these acceleration investigations are shown in figure 11.

The results obtained with the 0.0225-inch-diameter bleed compared favorably with those for the standard engine. At snap throttle opening from engine speeds of 600 and 1200 rpm, the engine accelerated slightly and then lost engine speed before finally accelerating uniformly. This loss in engine speed resulted from a slight leaning of the fuel-air mixture; the leaning, however, was not severe enough to cause backfiring. When the throttle was opened in 2 seconds, unsatisfactory acceleration characteristics were caused by lean operation when acceleration started from engine speeds of 600 and 900 rpm. Backfiring occurred during the acceleration from an engine speed of 900 rpm.

For rates of throttle opening of 4, 6, and 12 seconds, the acceleration characteristics were satisfactory except from an initial engine speed of 600 rpm. At this initial speed the engine speed usually increased slightly and then decreased 120 to 240 rpm before accelerating steadily. No backfiring was encountered at these conditions.

Concluding Remarks

Both carburetors, when modified, gave equally good acceleration characteristics when used with the injection impeller; however, the Ceco 58 CPB-3X carburetor probably gave better fuel distribution to the cylinders during the acceleration period because all the fuel is introduced through the injection impeller. Use of this carburetor also eliminated the presence of fuel in the combustion-air passage between the carburetor and the impeller and thus reduced the hazard of backfiring in this portion of the combustion-air system. As excellent performance could be obtained for the higher rates of acceleration, further improvement can undoubtedly be obtained by more extensive investigations of the optimum primary spring tensions and air-chamber capacities for the Ceco 58 CPB-4 carburetor and of the fixed-bleed diameter for the Ceco 58 CPB-3X carburetor. Although considerable backfiring occurred throughout the tests with both carburetors, none of the backfiring caused damage to the engine or combustion-air ducts.

SUMMARY OF RESULTS

An investigation of the acceleration of an R-3350 engine equipped with an NACA injection impeller and two different types of carburetor produced the following results:

1. Both the Ceco 58 CPB-4 hydraulic-metering carburetor, which had a vacuum-operated accelerating pump, and the Ceco 58 CPB-3X direct-metering carburetor, which had a throttle-actuated accelerating pump, were easily modified to produce generally satisfactory acceleration characteristics when used with an NACA injection impeller.

2. The vacuum-operated accelerating pump of the Ceco 58 CPB-4 carburetor was modified by the addition of 75 cubic centimeters to the air-chamber volume and by a reduction in strength of the primary spring to produce excellent acceleration characteristics at rapid throttle openings (2/3 and 2 sec) and satisfactory acceleration characteristics at slower throttle openings, except at the slowest throttle opening from engine speeds below 1200 rpm.

3. The throttle-actuated accelerating pump of the Ceco 58 CPB-3X carburetor was modified to produce satisfactory accelerations by replacing the standard 0.028-inch-diameter bleed in the load-compensator balance line with a smaller bleed of 0.0225-inch diameter.

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REFERENCE

1. Marble, Frank E., Ritter, William K., and Miller, Mahlon A.: Effect of the NACA Injection Impeller on the Mixture Distribution of a Double-Row Radial Aircraft Engine. NACA TN No. 1069, 1946.

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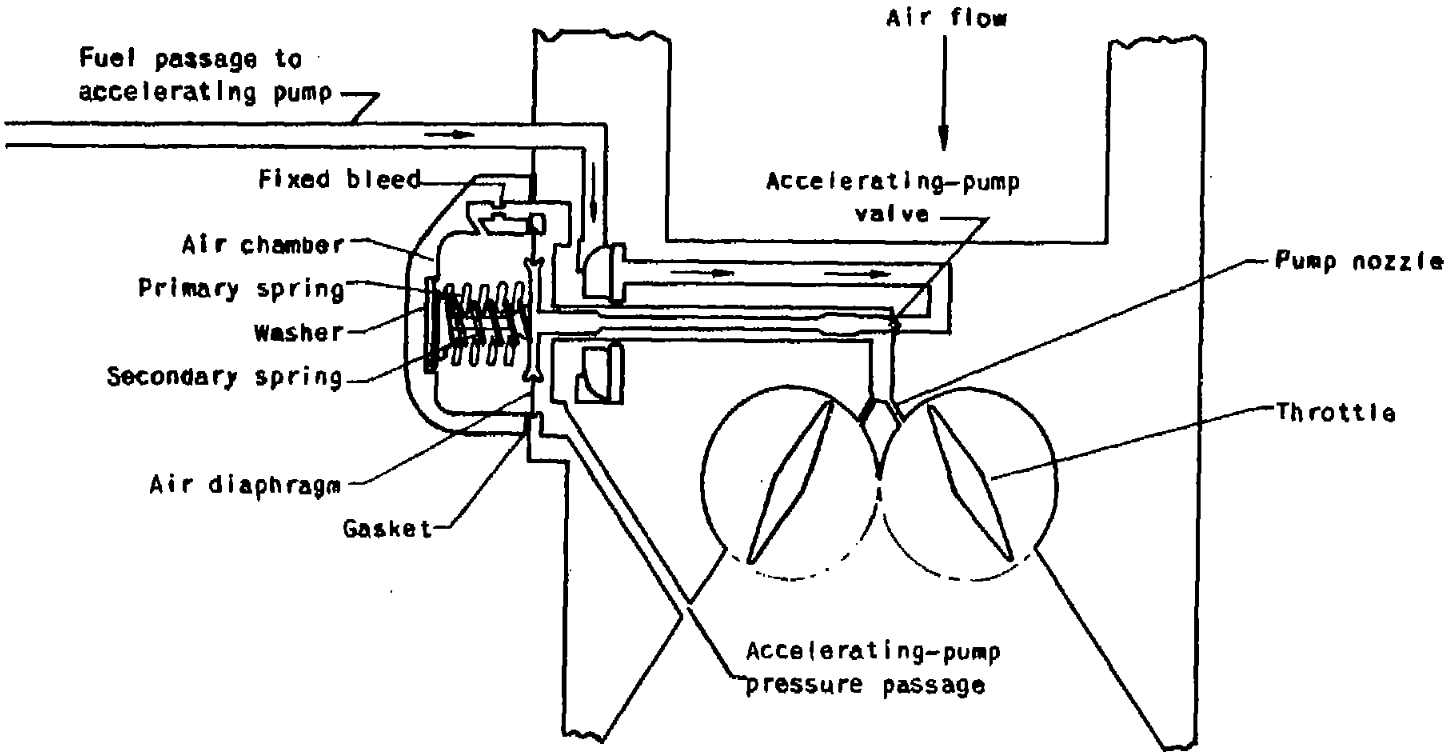

Figure 1. - Schematic diagram of vacuum-operated accelerating pump of CECO 58 CPB-4 hydraulic-metering carburetor.

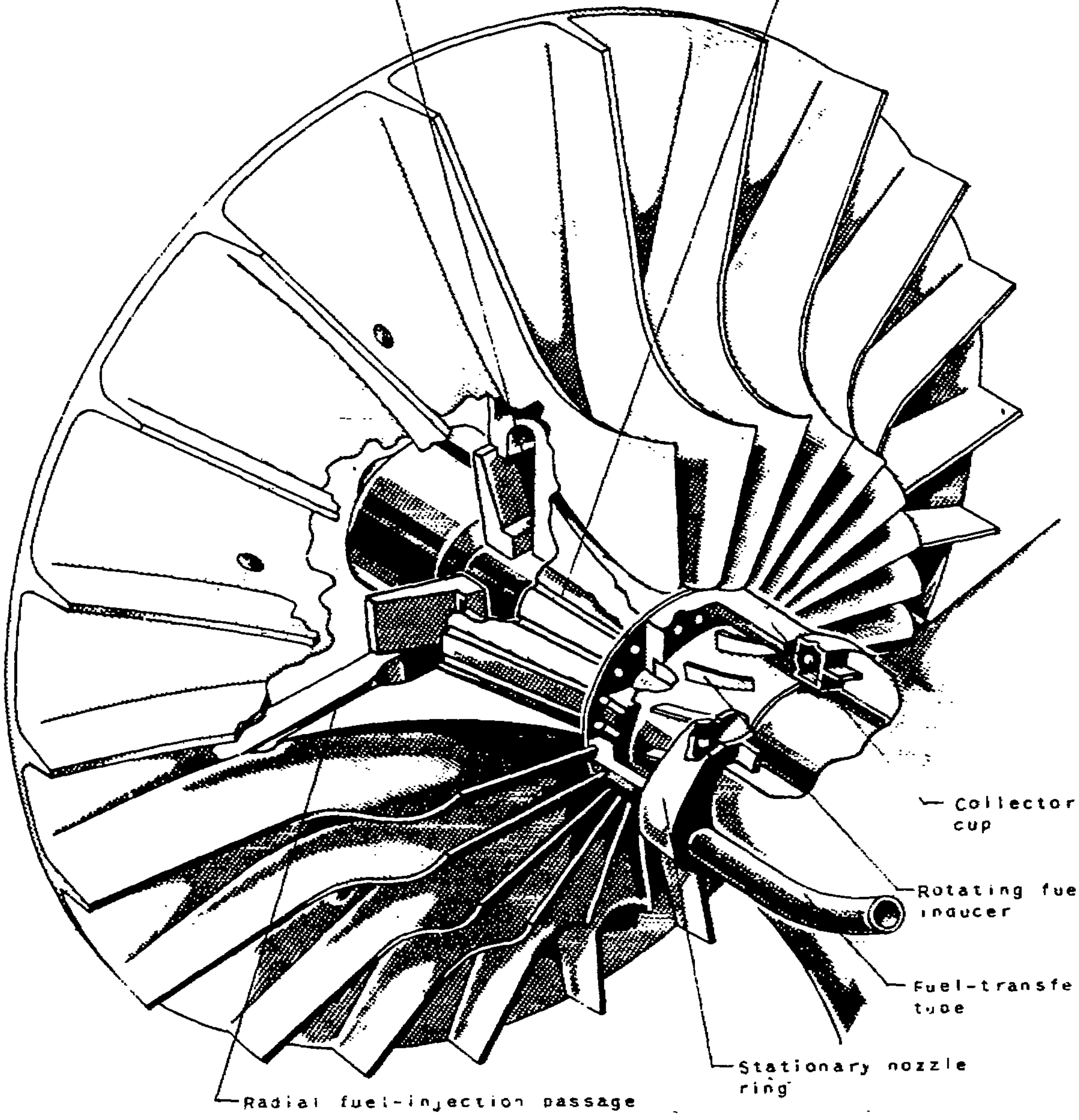

Figure 2. - NACA injection impeller designed for installation on R-3350 engine.

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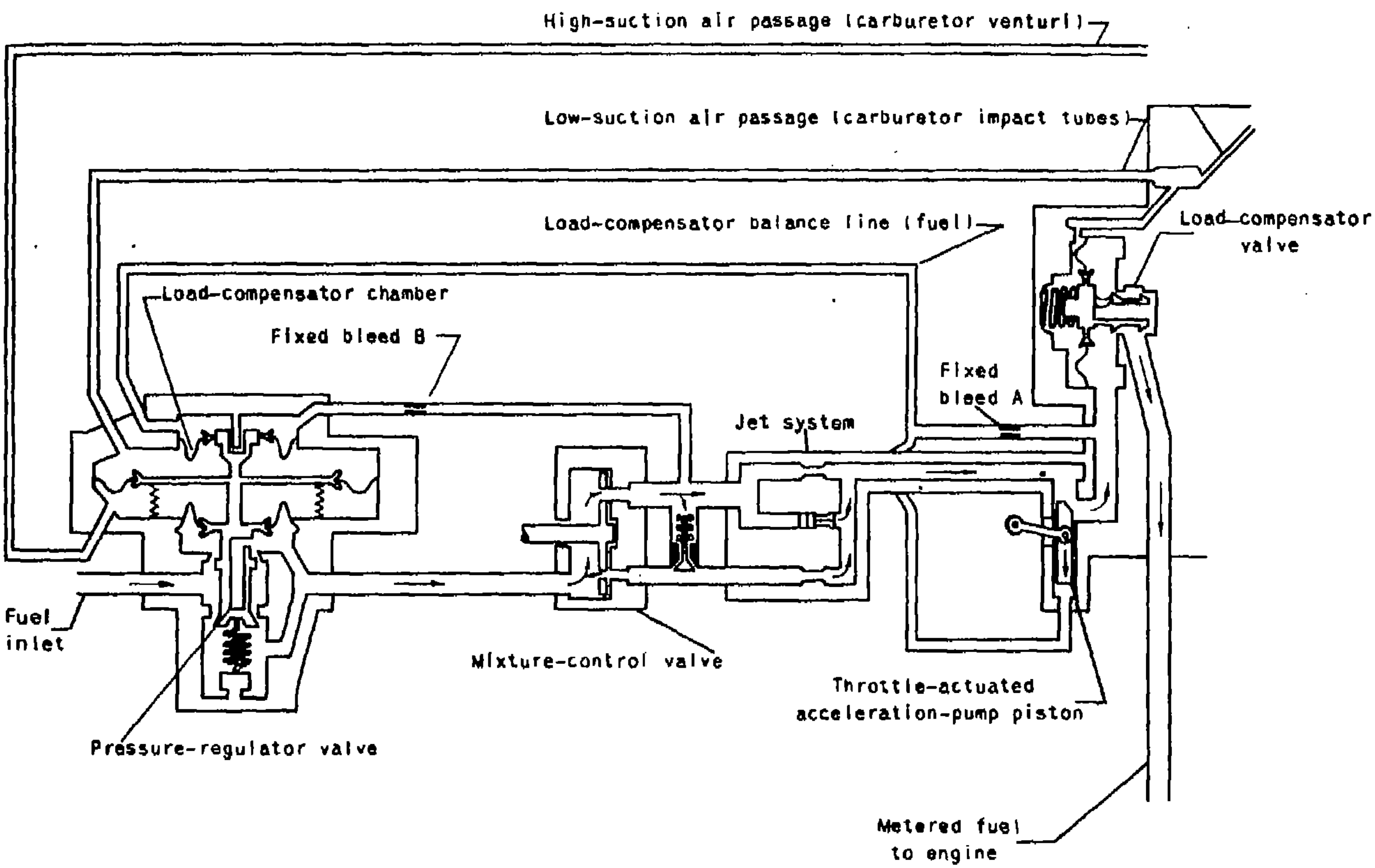

Figure 3. - Schematic diagram of throttle-actuated accelerating pump used in direct-metering CECO 58 CPB-3X carburetor.

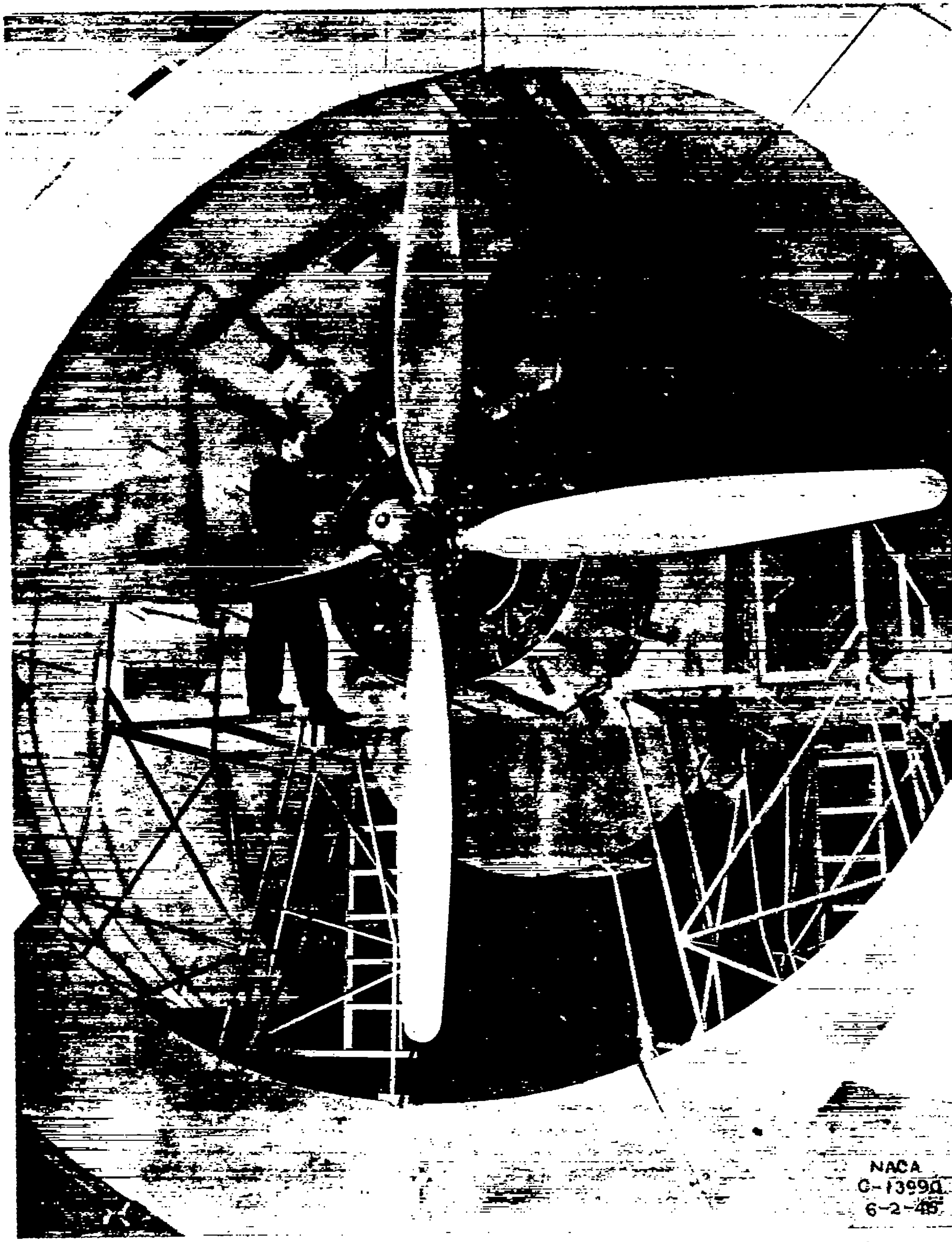

Figure 4. - Test-cell installation of R-3350 engine.

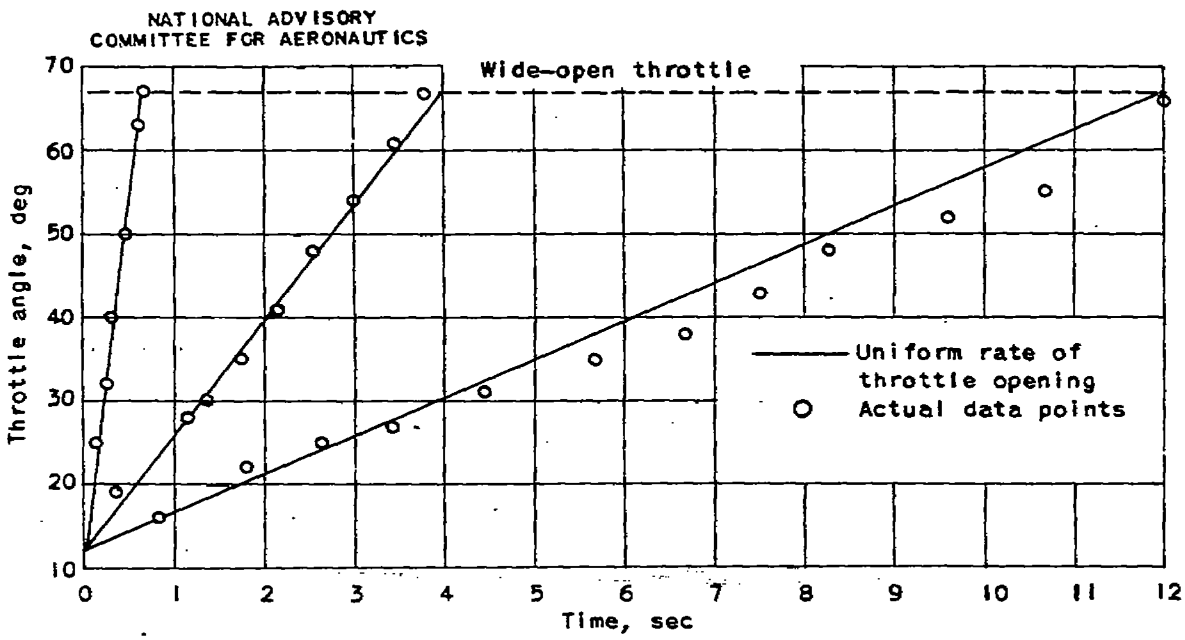

Figure 5. – Typical relation between throttle angle and time for three rates of throttle opening from initial engine speed of 900 rpm.

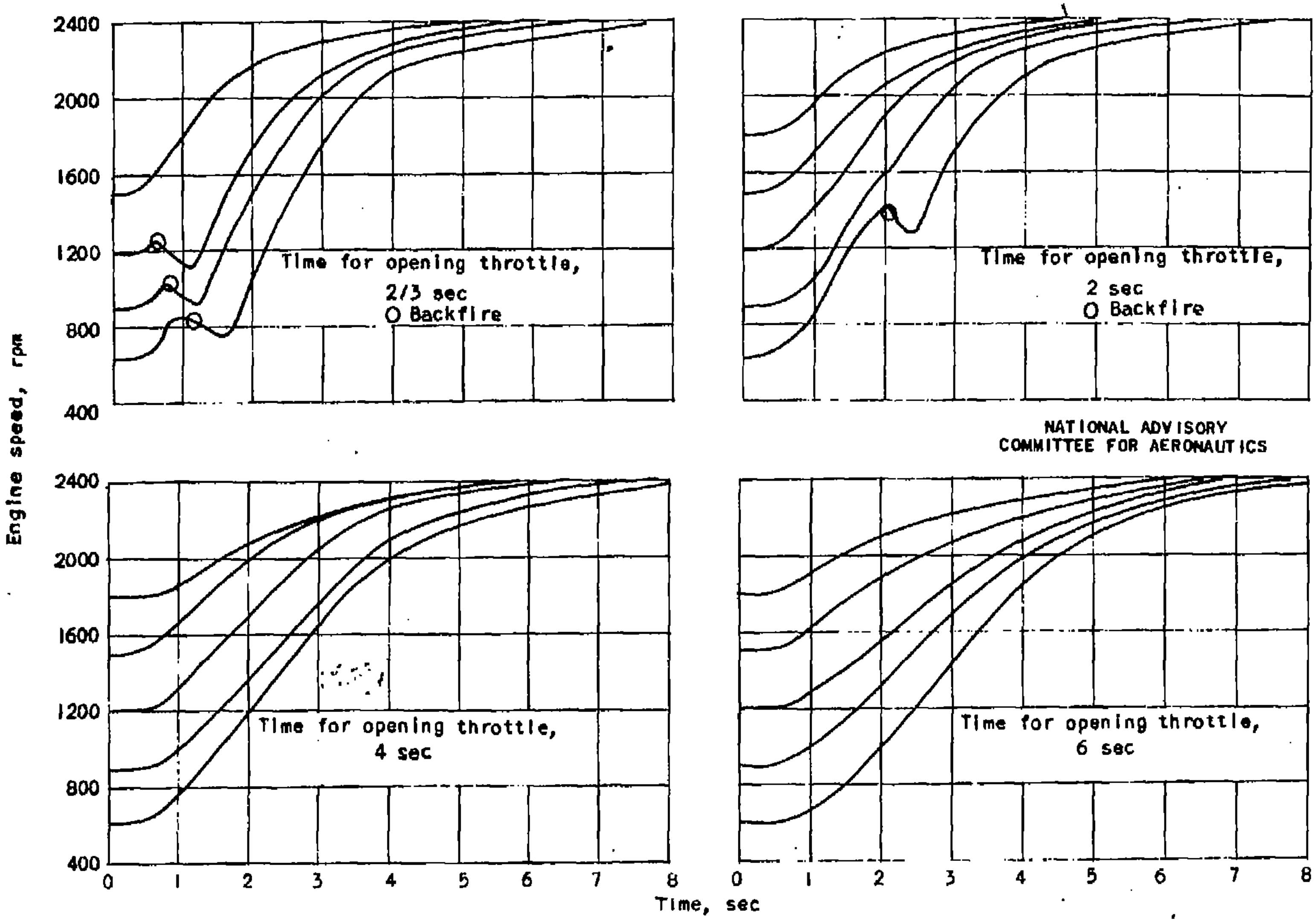

Figure 6. - Acceleration characteristics of R-3350 engine with standard nozzle bar and standard CECO 58 CPB-4 carburetor (configuration A).

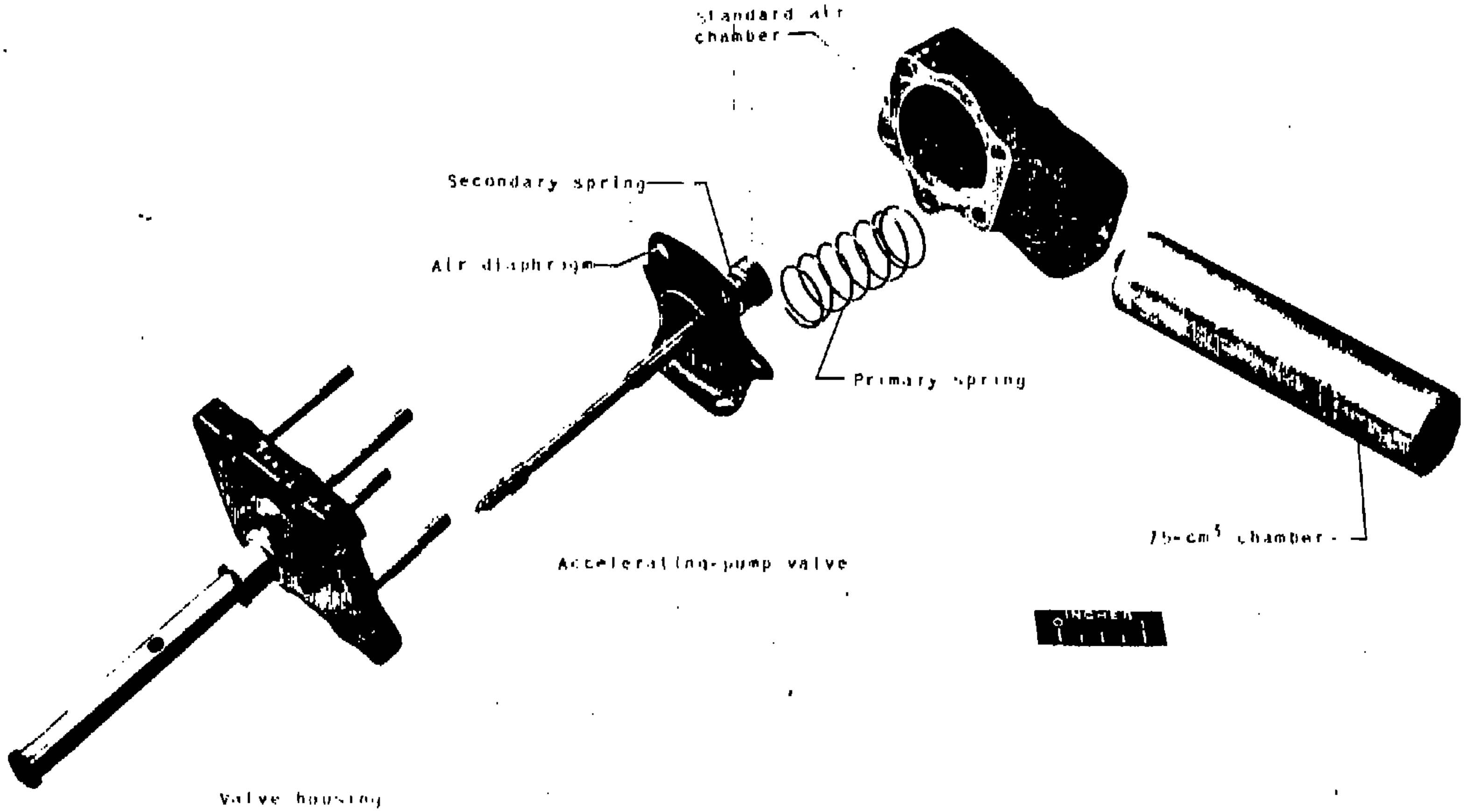

Figure 7. - Vacuum-operated accelerating pump and 75-cubic-centimeter air chamber.

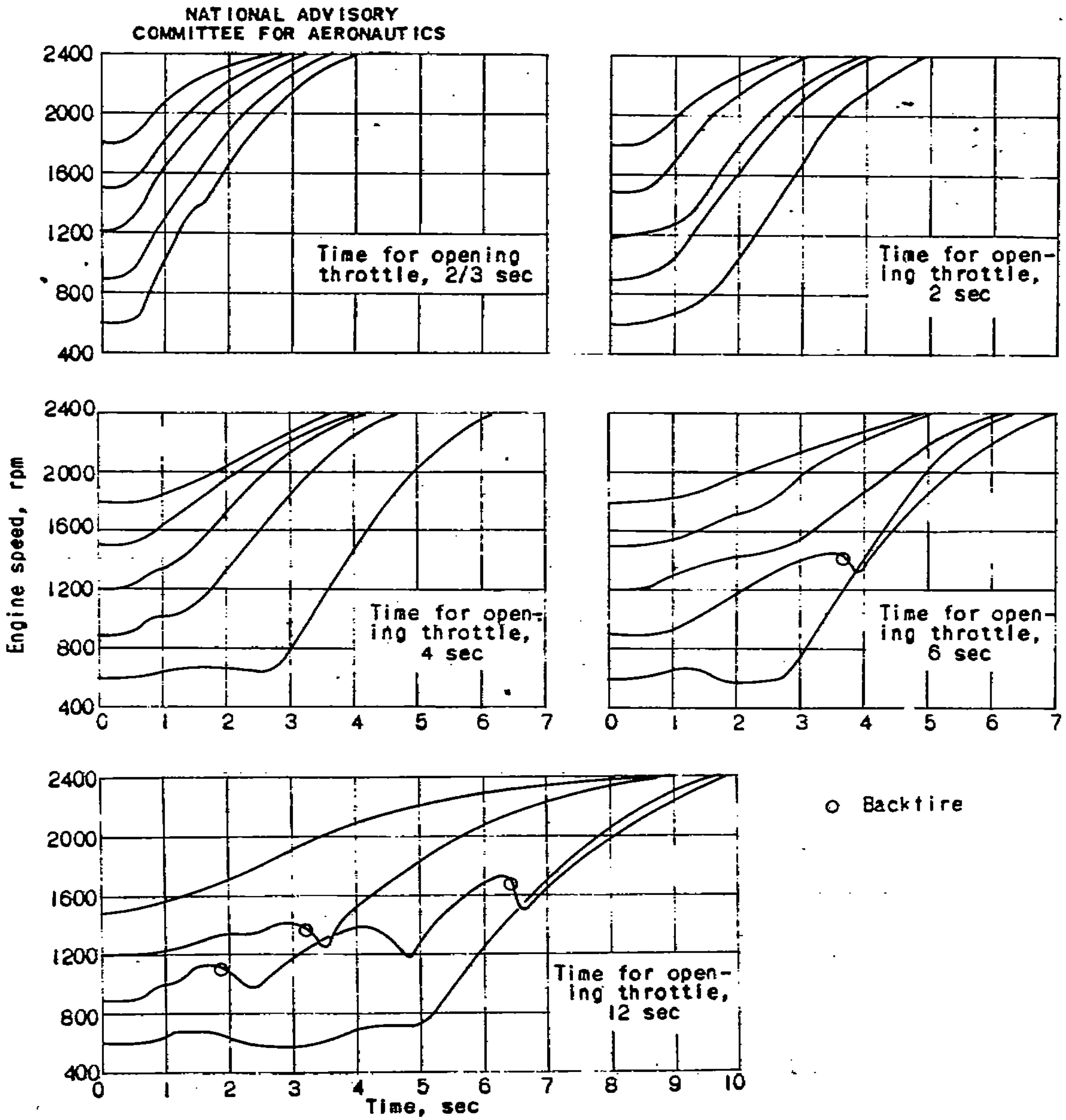

Figure 8. - Acceleration characteristics of R-3350 engine equipped with NACA injection impeller and modified CECO 58 CPB-4 carburetor (configuration B).

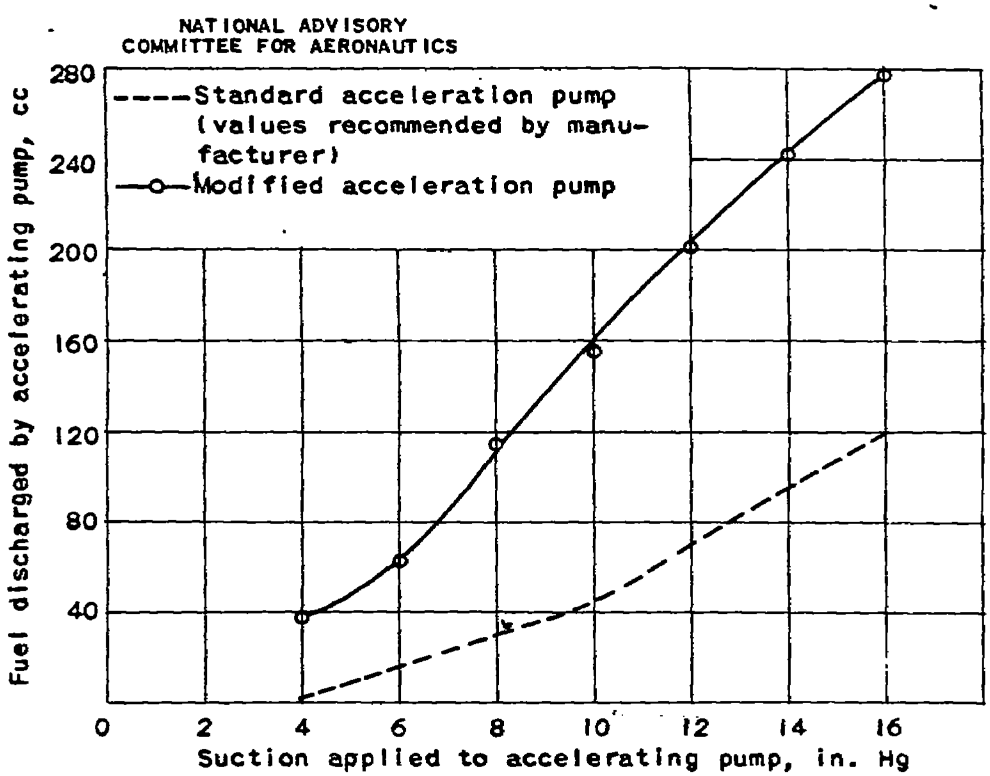

Figure 9. - Comparison of fuel-discharge quantities for standard accelerating pump of CECO 58 CPB-4 carburetor and modified accelerating pump for use with NACA injection impeller in R-3350 engine.

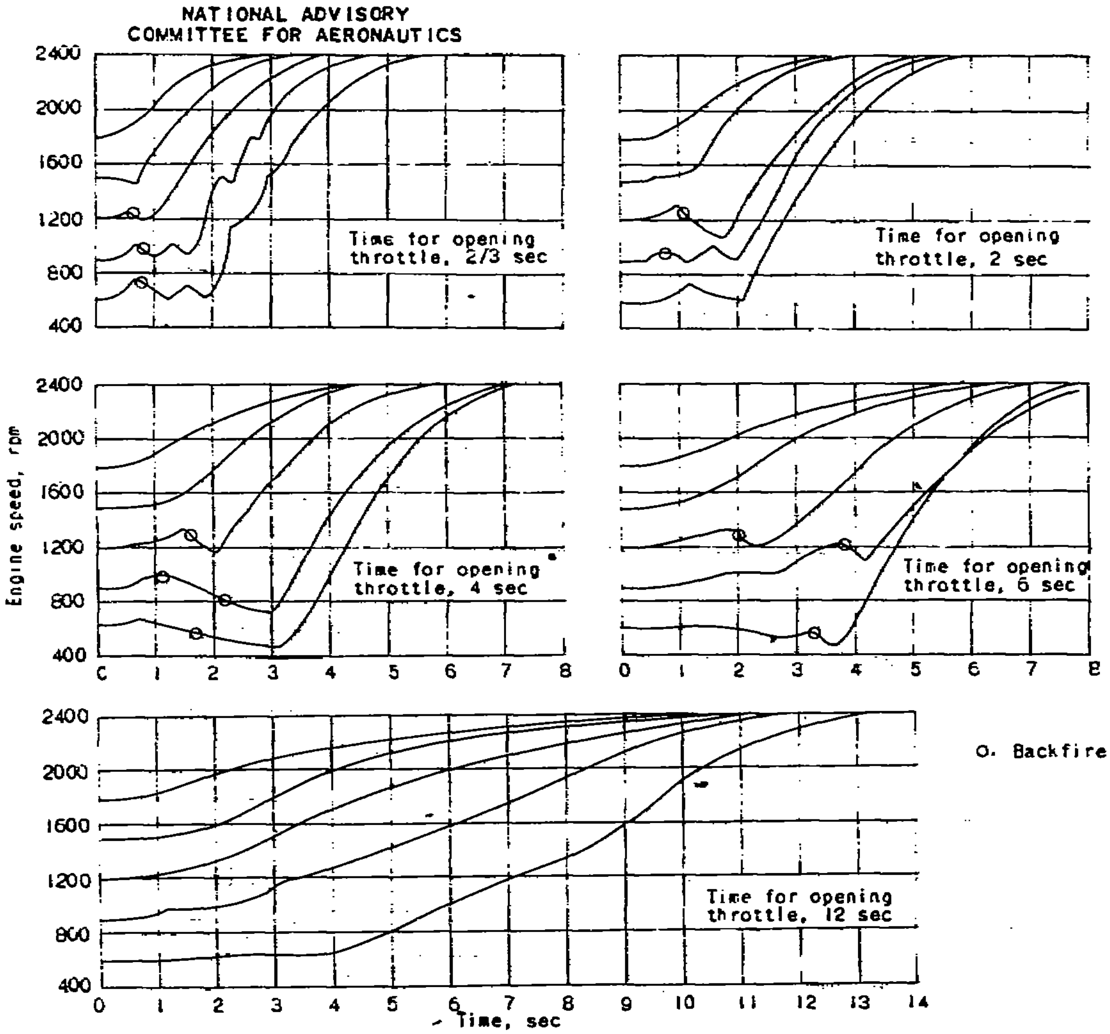

Figure 10. - Acceleration characteristics of R-3350 engine equipped with NACA injection impeller and standard CECO 58 CPB-3X carburetor (configuration C).

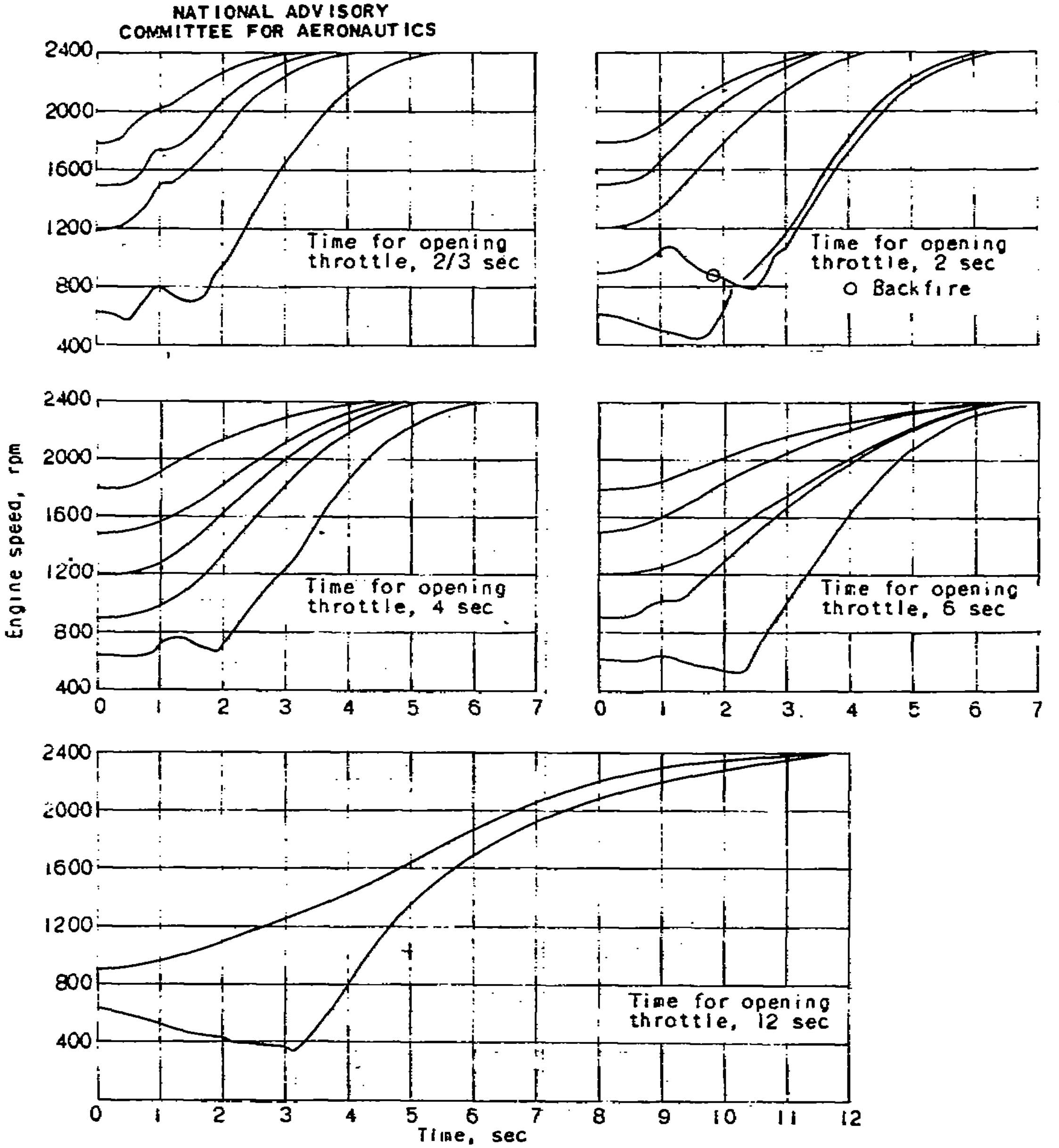

Figure 11. - Acceleration characteristics of R-3350 engine equipped with NACA injection impeller and modified CECO 58 CPB-3X carburetor (configuration C).

Aeaters (2)
Fuel injection systems
Impellers Fuel-injection-race
Fuel systems
Engines - Acceleration
Engines - Wright 3350.
Carburetor metering devices
Carburetors
Engines - Backfire
Fuel distribution