NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1637

EFFECT OF PREIGNITION ON CYLINDER TEMPERATURES

PRESSURES, POWER OUTPUT, AND PISTON FAILURES

By Lester C. Corrington and William F. Fisher

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SUMMARY

An investigation using a cylinder of a V-type liquid-cooled engine was conducted to observe the behavior of the cylinder when operated under preignition conditions. The effects of the following variables were investigated: fuel-air ratio, power output, aromatic content of fuel, engine speed, mixture temperature, and preignition source. The power outputs at which preignition would cause complete piston failure for the selected engine operating conditions and the types of failure encountered when using various values of clearance between the piston and the cylinder barrel were determined.

The results indicate that in the engine investigated preignition at high power levels led to backfiring into the induction system under most conditions. Preignition caused cylinder-head temperatures to increase up to 200° F at rates up to 30° F per second, caused maximum cylinder pressures to increase up to 30 percent, and caused power output to be drastically reduced. Runs to destruction indicated that preignition caused overheating that resulted in overexpansion of the piston, seizure of the piston in the cylinder barrel, and consequent melting of the side of the piston. By increasing the clearance between the piston and the cylinder barrel it was possible to increase the power level at which piston failure occurred because of preignition.

INTRODUCTION

Preignition difficulties experienced by the military services and engine manufacturers in recent years have indicated the need for information on the harmful effects of preignition and possible remedies. During an investigation of a V-type liquid-cooled engine at the NACA Cleveland laboratory, several cases of piston burning and destructive backfiring were encountered. Efforts to determine the cause of the failures showed that preignition was responsibile for a large number of them. Further investigations showed that

preignition in the engine was traceable to overheated spark plugs
and to overheated exhaust valves. Inasmuch as the preignition
problem appeared to be of great importance, an investigation was
undertaken at the Cleveland laboratory to obtain information on the
behavior of an engine during preignition operation.

With exhaust spark plugs and exhaust valves used as ignition
sources, preignition was excited at different fuel-air ratios,
power levels, engine speeds, mixture temperatures, and with fuels
containing various percentages of aromatics. Observations were
made of cylinder-head temperatures, preignition advance, engine
power, and change in peak cylinder pressure as the engine was
allowed to enter into preignition and remain operating under pre-
ignition conditions. Because of the unstable nature of preignition,
a motion-picture camera was used to record the data.

Several piston-destruction tests were run to determine the
type of piston failure associated with preignition and to deter-
mine the effect of a change of clearance between the piston and the
cylinder barrel on these failures.

APPARATUS

Engine setup. - A single-cylinder engine (bore, $5\frac{1}{2}$ in., stroke,
6 in.) was used in the investigation. The setup consisted of a
V-type liquid-cooled multicylinder engine block mounted on a
CUE crankcase in such a manner that any one of the cylinders could
be used. (See fig. 1.) One cylinder was used for all of the
investigation except the destruction tests, which were conducted on
different cylinders in the same bank. The induction system, the
main part of which is diagrammatically shown in figure 2, included
a pressure-regulating valve, a flow-measuring orifice installed
according to A.S.M.E. standards, a surge tank, a vaporization tank,
and an intake elbow designed to simulate the intake elbows on the
multicylinder engine.

Fuel was injected into the upstream end of the vaporization
tank in which seven inclined baffles promoted vaporization and
mixing with the air. The engine exhaust passed through a short
water-jacketed pipe into a large water-cooled muffler. The pres-
sure in the muffler was maintained constant at atmospheric pressure,
±1 inch of mercury.

The cylinder was cooled by a mixture of 30-percent ethylene
glycol and 70-percent water (by volume) circulated at the rate of
120 gallons per minute in a pressurized system. Navy 1120 lubri-
cating oil was used throughout the program; two oil jets located

on the major and minor thrust sides of the cylinder and directed toward the under side of the piston crown provided lubrication and piston cooling. The flow through each jet was about 4 pounds per minute for most of the tests. This flow value was arbitrarily chosen to insure sufficient cooling and lubrication and thereby eliminate any failure that might be caused by insufficient oil flow to the piston. The flow per jet was reduced to about 2 pounds per minute for the piston-destruction tests. This lower rate of oil flow probably more nearly simulates the multicylinder conditions for this engine.

The engine power was absorbed by an eddy-current type dynamometer and a direct-current motoring dynamometer. During negative torque operation, caused by advanced preignition, the dynamometer supplied power. An electronic speed regulator controlled the speed by varying the loading of these units. A balanced-diaphragm torque indicator with a remote-reading manometer was used. (See reference 1.)

Preignition source. - In most of the runs, spark plugs of various heat ranges were used as the source of preignition. One of these spark plugs was installed in the exhaust side with a colder-operating plug on the intake side. When excitation of preignition by the exhaust valves was desired, a valve (high chrome-nickel austentic steel, AMS-5700) with a badly corroded head was installed in place of one of the Nichrome-coated valves normally used in these tests and cold-operating spark plugs were installed in both spark-plug holes. Throughout the program the operating temperatures were never severe enough to cause scaling of the Nichrome-coated valves to the point where they would excite preignition.

Temperature measurements. - The cylinder-head temperature was measured with an iron-constantan thermocouple mounted about three-sixteenths inch from the inner wall of the combustion chamber between the two exhaust-valve seats and connected to a self-balancing potentiometer. A check was made on the rate of response of the potentiometer and it was found to be sufficiently high to record the rate of cylinder-head-temperature rise during preignition. Spark-plug electrode temperatures were measured with a chromel-alumel thermocouple mounted in the center electrode of the intake plug about one-sixteenth inch from the firing end. This installation was possible only with certain types of spark plug and for this reason the spark-plug-electrode temperature was measured for only a few of the tests. The design of the exhaust pipe prevented the use of a thermocouple in the exhaust spark plug.

Electronic equipment. - A piezoelectric pickup, installed near the intake spark plug and coupled to an oscilloscope through an

amplifier, provided pressure-time diagrams. A special timing
device indicated on the oscilloscope trace the positions of 180°,
120°, and 60° B.T.C., top center, and 60° A.T.C. In order to deter-
mine the time of ignition, the spark gap of the exhaust spark plug
was connected to serve also as an ionization gap. When the gap
became ionized because of the presence of a flame, a current sup-
plied by an electronic instrument was permitted to flow through it.
By suitable connections with this electronic instrument, a vertical
line was superimposed on the oscilloscope trace, which indicated
the presence of the flame at the spark plug. Inasmuch as this same
spark plug was used as the preignition source in most of the runs,
the ionization-gap trace together with the timing marks made it
possible to determine the approximate ignition advance during pre-
ignition operation.

Data-recording equipment. - A 16-millimeter motion-picture
camera was set up to photograph simultaneously the oscilloscope
trace and indications of engine speed, time, engine torque, spark-
plug-electrode temperature, and cylinder-head temperature. Photo-
graphs were taken at the rate of eight frames per second throughout
each preignition run. Reproductions of three frames, representing
three successive stages in a typical preignition run, are shown in
figure 3.

Fuels. - Because aromatic fuels are, in general, more suscep-
tible to preignition than paraffinic fuels, the aromatic content
was chosen as the variable in selecting fuels. In order to pre-
clude the possibility of knock under all test conditions, the fuels
were blended to have a very high performance number. The following
blends, all leaded to 6.0 ml TEL per gallon, were used to obtain
the data:

Fuel	Percentage composition by volume			
	Cumene (aromatic)	Triptane	S-reference fuel	Hot-acid octanes
1	0	50	----------	50
2	15	35	50	--------
3	30	20	50	--------
4	50	0	50	--------

Hot-acid octanes were used in place of S-reference fuel in fuel 1
because of a temporary shortage of S-reference fuel. The 30-percent
cumene blend (fuel 3) was used for all runs in which aromatic con-
tent was not a variable.

PROCEDURE

For the preignition program reported herein the following basic operating conditions were used as the basis for comparing, at a variety of engine conditions, the behavior of the engine under preignition operation: fuel-air ratio, 0.070; engine speed, 3000 rpm; mixture temperature, 175° F; and fuel, 30-percent cumene blend. The values for each of the variables and the values of the operating conditions that were held constant are listed in the following table:

Variable	Approximate imep (lb/sq in.)	Fuel-air ratio	Cumene in fuel (percent)	Source of pre-ignition	Engine speed (rpm)	Mixture temperature (°F)
Fuel-air ratio	300	0.070 .099	30	Spark plug	3000	175
Power output	300 250 185	0.070	30	Spark plug	3000	175
Aromatic content of fuel	250	0.070	0 15 30 50	Spark plug	3000	175
Engine speed	250	0.070	30	Spark plug	3000 2000	175
Mixture temperature	250	0.070	30	Spark plug	3000	175 275
Source of pre-ignition	300	0.070	30	Spark plug, exhaust valve	3000	175

The following operating conditions were maintained constant:

Outlet-coolant temperature, °F 250
Inlet-oil temperature, °F 185
Inlet-valve timing, degrees B.T.C.
  Opening 48
  Closing 118
Exhaust-valve timing, degrees A.T.C.
  Opening 104
  Closing 26
Spark timing, degrees B.T.C.
  Inlet 28
  Exhaust 34
Compression ratio 6.65

Friction data were obtained by motoring the engine after a preignition test with the fuel shut off.

Several sources of preignition (exhaust spark plugs and corroded exhaust valves) were rated by operating the engine at the basic set of conditions and increasing the manifold pressure until preignition was encountered. The power level was noted at this point and taken as the rating of the preignition source. In order to obtain preignition at a given power level, it was then necessary only to choose the appropriate spark plug or exhaust valve. Several runs could usually be made before an appreciable change in rating made it necessary to replace the preignition source.

When a run was to be made, the engine was operated at the desired power level but with the fuel-air ratio considerably richer than 0.070. When operating conditions were steady, the fuel flow was slowly decreased until the engine was running at the basic fuel-air ratio (0.070) where preignition was encountered. The engine was permitted to run under preignition conditions until the test was terminated by backfiring. The camera used for recording data was started before preignition was encountered and the instrument readings were photographed during the complete test run. Fuel-flow and air-flow measurements were taken at the start of preignition. Although the fuel flow remained constant throughout a run, the air flow decreased a small amount because of the higher cylinder temperatures that accompanied preignition. The increase in fuel-air ratio during a run is estimated to have been a maximum of about 4 percent.

In those runs where preignition was investigated at a fuel-air ratio richer than 0.070, a spark plug with a lower preignition rating than the one used in the runs at a fuel-air ratio of 0.070

was installed in the engine. The engine was brought up to the same conditions in the same manner as in the runs at a fuel-air ratio of 0.070 and was operated with a rich mixture until operation was stable. The fuel flow was slowly decreased until preignition was encountered, which occurred at a fuel-air ratio of 0.099. These runs were terminated when the preignition stabilized in the vicinity of bottom center.

Valve-preignition runs were conducted with cold-type spark plugs installed in the engine so that the only probable source of preignition would be a corroded exhaust valve installed for that purpose. The corroded exhaust valve was preignition-rated and the runs were made at the basic operating conditions.

Four destruction runs were made at high-power levels under conditions of preignition with different clearances between the piston and cylinder barrel. The purpose of these runs was to determine the type of failure that could be expected from preignition. The clearances used, as determined by measurements of the bore and of the piston at the top of the skirt were 0.017, 0.021, 0.026, and 0.034 inch. The normal clearance for the engine is 0.021 inch. Using an exhaust spark plug as the source of preignition, these runs were conducted in the same manner as described for the foregoing preignition runs. Because a rich mixture was used, no backfiring was encountered, which together with higher power output and less piston cooling (reduced oil-jet flow) resulted in the runs being terminated by piston failure.

RESULTS AND DISCUSSION

Reproducibility of preignition runs. - The behavior of an engine during preignition operation is dependent to some extent on the design of the cylinder and on the location and the heat capacity of the preignition source. Even when these factors and all operating conditions are maintained constant, however, there is a certain amount of irreproducibility between successive preignition runs. The greatest factor of irreproducibility in the investigation reported herein, when a spark plug was used as the source of preignition, was the time required for the preignition to advance from the normal spark timing to a point about 60° B.T.C. A preignition run would usually start with ignition a few degrees early on occasional cycles. As these cycles with early ignition became more frequent, the time of ignition became earlier. During this period the cylinder temperature rose very slowly. After the time of ignition in most of the cycles had advanced to about 60° B.T.C., the preignition process became greatly accelerated and

from this point on successive runs were fairly reproducible. The
time required for preignition to become advanced to this critical
point (about 60° B.T.C.) varied from 30 to 60 seconds in successive
runs. The reason for this variation may lie in slight changes in
the condition of the hot spark plug from one run to the next due to
deposits and corrosion, or it may be due to small errors in setting
the engine conditions. A few other engines are known to have this
characteristic and it has caused some difficulty in obtaining
reproducibility during the preignition rating of fuels.

   Typical preignition runs. - A plot of five preignition runs at
approximately the same operating conditions is shown in figure 4.
The time scale used is arbitrary; the curves were so adjusted along
the scale that the points where preignition became rapidly acceler-
ated (time of ignition about 60° B.T.C.) coincided. Comparisons
between the curves are made easier in this manner by eliminating
from consideration the period of poor reproducibility. The loca-
tion of the zero point on the time scale therefore has no signifi-
cance. Figure 4, then, shows the reproducibility of the preigni-
tion runs after preignition had begun to advance rapidly.

   In most cases data were taken from the frames of the motion-
picture film that showed operating conditions at 1-second intervals;
data showing rapidly changing conditions were taken at shorter
intervals. The percentage increase in the peak pressure at any
instant over that for normal combustion was obtained from the
relative height of the pressure-time diagrams as measured from the
photographs of the oscilloscope screen. The accuracy of the
height measurement is estimated to be about 5 percent. The meas-
ured values of indicated mean effective pressure are not correct
where the rate of change is rapid because of inertia of the manom-
eter fluid and because of the speed-regulation characteristics of
the dynamometer used.

   The curves shown in figure 4 have been faired to represent an
average of the individual runs and are considered to be typical of
the behavior of the engine during preignition at the given set of
operating conditions. All the curves presented have been obtained
in this manner from several runs at each operating condition. For
the sake of simplicity the original data are shown only in figure 4.

   Backfiring. - Most of the runs for which data are presented
were terminated by backfiring into the induction system. The point
at which backfiring occurred is indicated by arrows on the curves.
In order for preignition to cause backfiring, the time of ignition
must be considerably earlier than that at which the intake valves
close (118° B.T.C.). Enough pressure rise must take place to slow

down greatly, or even reverse, the flow through the intake valves
before the flame can pass into the induction system.

Whenever a backfire was encountered, the entire contents of
the vaporization tank burned causing a large pressure rise and a
subsequent reversal of the air flow at the entrance to the vaporiza-
tion tank. Because the fuel was injected at this point (fig. 2),
the flame burned itself out very quickly. About 1 second was
required after the backfire for combustion in the cylinder to
become reestablished; however, the preignition source in the com-
bustion chamber would still be hot enough to cause very early igni-
tion and backfiring would continue to occur at short intervals
until the operating conditions were so changed that the preignition
source was cooled.

At high power output, preignition led to backfiring into the
induction system at fuel-air ratios leaner than about 0.095. At
mixtures richer than this value, preignition became stable with
ignition occurring in the vicinity of bottom center.

Effect of fuel-air ratio. - Combustion temperatures and rate
of burning are controlled by several variables, one of the most
important being fuel-air ratio. Because the behavior of an engine
during preignition operation depends largely on these two factors,
fuel-air ratio is an important variable in a consideration of pre-
ignition. Figure 5 shows typical preignition curves for a lean
and a rich mixture at the same power level. At the lean mixture
a period of about 7 seconds was required from the time rapidly
advancing preignition began until backfiring was encountered. At
this point the time of ignition had advanced to about 220° B.T.C.
(40° B.B.C.). At the rich mixture, however, the time of ignition
did not advance so rapidly and became more or less stable at 150°
to 160° B.T.C. The engine did not backfire at the rich mixture.

The increase in peak cylinder pressure due to preignition was
about 20 percent at the lean mixture and 25 percent at the rich
mixture. Because of the scatter of the data involved in this meas-
urement (fig. 4), the difference between these two values may not
be significant.

The power output of the cylinder dropped very sharply when pre-
ignition reached an advanced stage. At the lean mixture, the power
output was changing so rapidly at the time the engine backfired
that the measurements cannot be considered reliable; runs at other
engine conditions, however, have shown that the power output often
becomes negative (power is drawn from dynamometer) when ignition
takes place before bottom center. At the rich mixture the power
output dropped more than 80 percent before preignition became stable.

The cylinder temperature increased more rapidly at the lean
mixture than at the rich mixture but the backfiring point was
reached so quickly that the total rise was only about 150° F as com-
pared with 200° F at the rich mixture. The rate of cylinder-head-
temperature rise at the lean mixture was about 30° F per second.
The piston temperature might be expected to follow curves similar
to those shown for the cylinder-head temperature with the proba-
bility that the temperature rise would be even greater. The reason
for piston seizure or melting as a result of preignition is there-
fore evident.

Effect of power output. - Typical preignition runs at three
power levels (obtained by using spark plugs of three different
heat ranges) are shown in figure 6. The main effect of increased
power output was to increase the rapidity with which changes took
place. Backfiring terminated all three runs but at the lowest
power output a much longer time was required before the backfire
occurred. The power output for the lowest initial power runs
dropped 65 percent before backfiring occurred and for the two high
initial power runs dropped to approximately zero before backfiring
took place; the cylinder-head temperature at the time of backfiring
was about the same for all three runs. Peak cylinder pressure was
increased 20 to 30 percent during preignition with some indication
that the percentage increase varied inversely with the power level.

Effect of aromatic content of fuel. - The preignition rating
of a fuel depends to a large extent on its aromatic content. At
the conditions investigated, however, the percentage of aromatics
in the fuel had only a small effect on the behavior of the engine
after preignition was excited (fig. 7). The peak-pressure-increase
curves show the greatest effect with a trend toward a direct rela-
tion between aromatic content and peak-pressure increase.

The same spark plug was not used as the preignition source for
all of the runs shown, therefore the slight variation in the power
level at which preignition was obtained has no relation to the fuel
composition. Instead, spark plugs of the same type but having
slightly different operating temperatures were selected to give
preignition at the same approximate power level for the four fuels.

A curve is also included in figure 7 that shows the changes in
the temperature of the center electrode of the intake spark plug
during a preignition run. This spark plug was of a colder-operating
type than that used in the exhaust side as the preignition source.
The temperature of this intake plug increased approximately 550° F
before backfiring was encountered. Because of difficulties involved
in obtaining measurements of this temperature, the data shown are
the only data available.

Effect of engine speed. - Data from runs at two engine speeds, 3000 and 2000 rpm, are shown in figure 8. Both runs were at approximately the same indicated mean effective pressure with spark plugs of the same type but of slightly different thermal ratings. The ignition advance required to cause backfiring was almost the same at both engine speeds.

The increase in peak cylinder pressure due to preignition was only about 15 percent at 2000 rpm, as compared with 25 percent at 3000 rpm. This difference can be at least partly accounted for by the increased amount of heat transferred per cycle due to the greater time available at the lower engine speed.

The rate of cylinder-head-temperature rise was about the same at both engine speeds but the total rise was less at the lower speed because the engine backfired more quickly.

Effect of mixture temperature. - At approximately constant power output, mixture temperature had little effect on the behavior of the engine during preignition operation (fig. 9). At the higher mixture temperature of 275° F, the engine appeared to backfire a little more readily, probably because of better vaporization. The peak-pressure increase was greater at the lower mixture temperature of 175° F. Trouble was experienced with the ionization-gap trace (ignition indicator) during the runs at a mixture temperature of 275° F and therefore the time-of-ignition curve for these runs (fig. 9) is incomplete.

Effect of preignition source. - A comparison of preignition resulting from a hot spark plug and from a hot exhaust valve is shown in figure 10. When the hot exhaust valve was used, preignition advanced much more slowly than when the hot spark plug was used. Several minutes were required before preignition from the exhaust valve reached the point where it became rapidly accelerating. At the plotted zero point on the time scale, preignition was already in progress with the hot exhaust valve and had caused the cylinder-head temperature to rise approximately 50° F, whereas preignition had not yet begun with the hot spark plug. No satisfactory method of determining the time of ignition when the exhaust valve was the source was available, therefore the curve showing time of ignition is omitted from figure 10. From inspection of the power-output curves, however, it is apparent that backfiring took place with a less advanced time of ignition when the exhaust valve was the preignition source. This less-advanced time of ignition may explain the reason that the peak-pressure increase is lower for the exhaust-valve preignition than for the spark-plug preignition. These occurrences can be accounted for by the fact that the exhaust valves are much closer to the intake valves than is the exhaust spark plug.

Engine difficulties experienced. - The previously mentioned runs were made with a stock piston, the diameter of which had been reduced 0.005 inch. With this added piston clearance, the only part failures encountered involved the spark plugs and the intake valves. After engine operation under some of the preignition conditions, the center electrode of the exhaust spark plug was found to be burned or melted. On two occasions one of the intake valves was found to be burned (fig. 11). Although piston-ring wear was more rapid than normal, no other failures were experienced in more than 500 preignition runs of the type discussed.

Types of failure caused by preignition. - Photographs of piston failures that resulted from preignition runs to destruction are presented in figure 12. These runs were conducted with reduced piston cooling (lower oil-jet pressure) and at generally higher power levels than those of the runs previously discussed. The pistons shown were tested with different side clearances between the piston skirt and the cylinder barrel. A spark plug with the desired operating temperature was installed in the exhaust side and used as the preignition source for each run.

The clearance for the first run was about 0.004 inch less than the normal value (0.021 in.) for the engine. In this run, preignition caused overheating that resulted in piston seizure and consequent melting of the side (fig. 12(a)). With the normal clearance, a higher power level was necessary to cause failure but the failure was of the same nature (fig. 12(b)). The general temperature level of the piston at the time of seizure was apparently higher, however, and a small amount of local melting took place in the center of the crown. When the clearance was increased to 0.005 inch greater than normal, the failure was still a seizure with consequent melting of the side (fig. 12(c)) but more local melting took place in the center of the crown than with normal clearance. A further increase of the clearance to 0.013 inch greater than normal eliminated the seizure (fig. 12(d)) and complete failure was not experienced at the power level investigated. Slightly more severe local melting, however, took place in the center of the crown. On the basis of these runs and a number of unreported preignition investigations, when piston failure is caused by preignition the type of failure depends mainly on the clearance between the piston and the cylinder. With small clearances, the failure occurs through seizure and consequent melting of the side; whereas if the clearances are large enough, melting will probably occur wherever the piston is hottest, in the center of the crown in this instance.

The indicated mean effective pressure required to cause piston destruction due to preignition as a function of clearance between the piston and the cylinder is shown in figure 13. Although the fuel-air ratios for the four runs were slightly different, the differences were small enough to be of no great importance. The points show that piston clearance is an important factor in preventing piston failures due to preignition. Determination of how near the piston cooling used for these destruction runs was to that used in the multicylinder engine is impossible; however, such a curve for other cooling conditions would undoubtedly show a similar trend.

Photographs of damage to other cylinder parts that accompanied the piston failures in two of the runs are also presented. Figure 14 shows an exhaust valve that burned at the time of the piston failure shown in figure 12(b). Inasmuch as two other runs were made at more severe operating conditions without valve failure, it is felt that this failure was brought about by particles of aluminum or other substance lodging between the valve and its seat. Figure 15 shows the damage to the cylinder barrel that accompanied the piston failure shown in figure 12(c). The torching action of the hot gases burned through the barrel into the coolant passage.

SUMMARY OF RESULTS

The results of the investigation conducted on a V-type liquid-cooled engine to determine the effect of preignition on cylinder temperatures, pressures, power output, and piston failures are summarized as follows:

1. At high power output, preignition led to backfiring into the induction system at fuel-air ratios leaner than about 0.095. At mixtures richer than this value, preignition became stable with ignition occurring in the vicinity of bottom center.

2. Destruction runs indicated that, with normal clearance between the piston and cylinder barrel, preignition caused overheating that resulted in overexpansion and seizure of the piston in the cylinder barrel with consequent melting of the side of the piston.

3. With increased clearance between the piston and the cylinder barrel, piston seizure due to preignition could be eliminated, and the power level at which piston failure occurred could be raised. The runs indicated that without seizure the failure would probably occur through melting of the center of the piston crown.

4. Cylinder-head-temperature increases up to 200° F and rates of cylinder-head-temperature rise up to 30° F per second were experienced.

5. Preignition caused maximum cylinder pressures to increase 10 to 30 percent.

6. Preignition caused power output to drop 65 to more than 100 percent. (Power was drawn from a dynamometer when engine power became negative.)

7. The aromatic content of the fuel had only a small effect on the behavior of the engine after preignition was excited. The greatest effect was in the peak-pressure increase, the trend being toward a direct relation between aromatic content and peak-pressure increase.

8. Preignition originating at an exhaust valve advanced more slowly than preignition originating at a spark plug but the end result was not greatly different.

9. Changes in engine speed and in mixture temperature had very little effect on the behavior of the engine during preignition operation.

Flight Propulsion Research Laboratory,
     National Advisory Committee for Aeronautics,
          Cleveland, Ohio, March 8, 1948.

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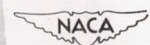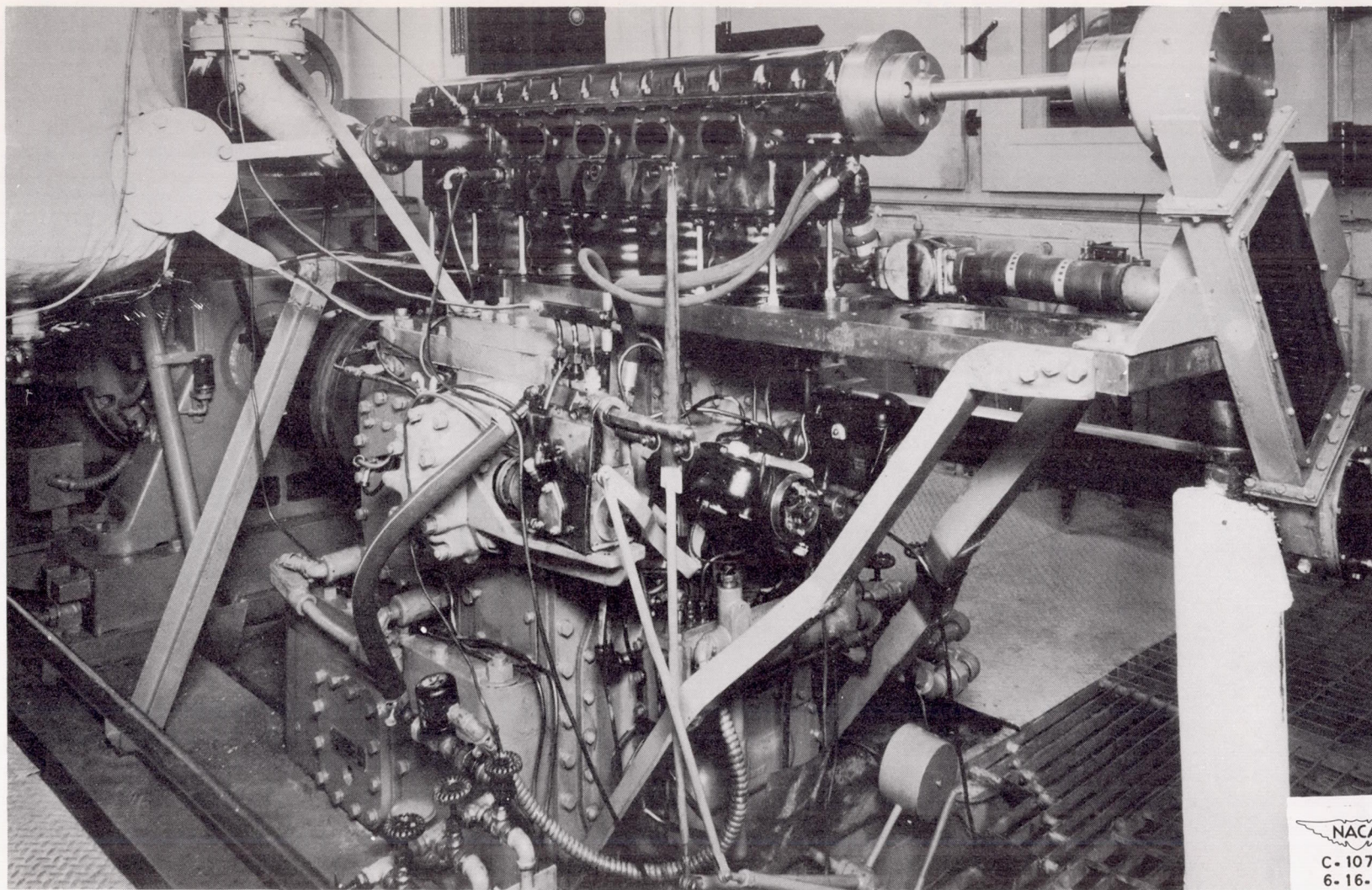
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Figure 1. — Single-cylinder test engine showing intake side of multicylinder engine block mounted on CUE crankcase.

Inlet-air thermocouple

Fuel-injection nozzle

Vaporization tank

Inlet-air pressure tap

Multicylinder-engine block

Mixture thermocouple (bare wire)

Surge tank

Intake elbow

NACA
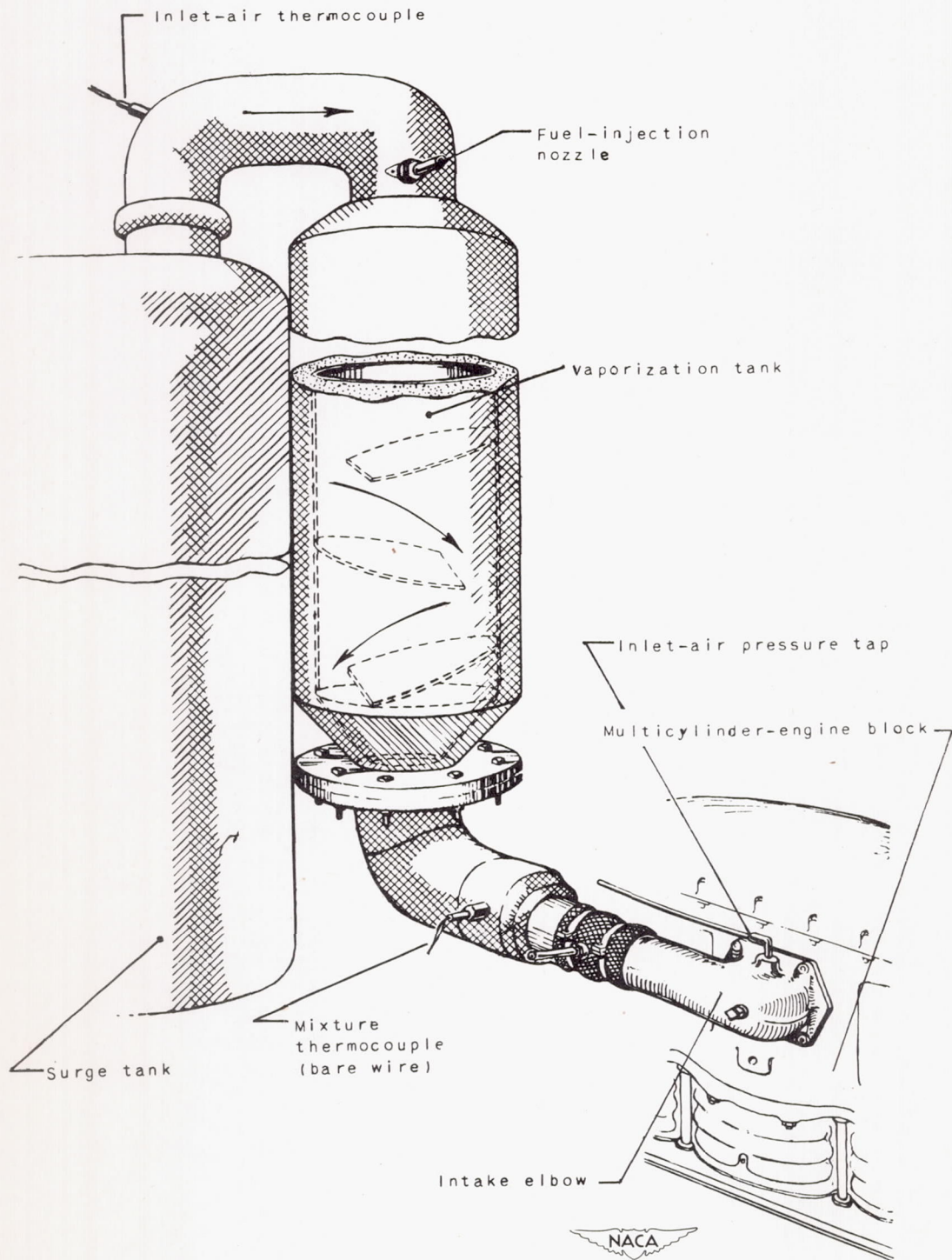
Figure 2. – Induction system used with single-cylinder test engine.

Timing marks

Ionization-gap trace
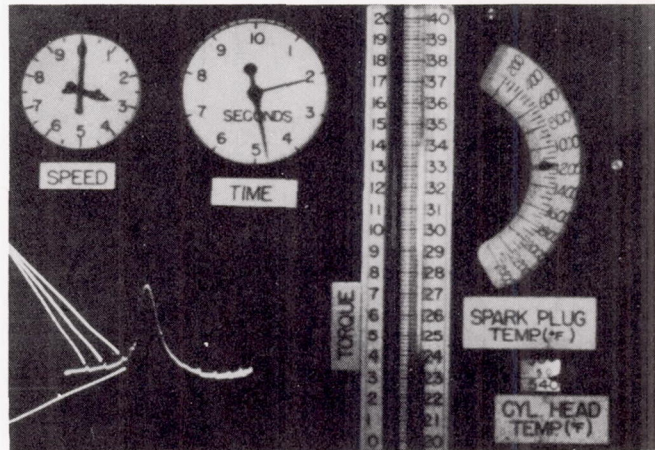
(a)   Normal ignition.

Ionization-gap trace
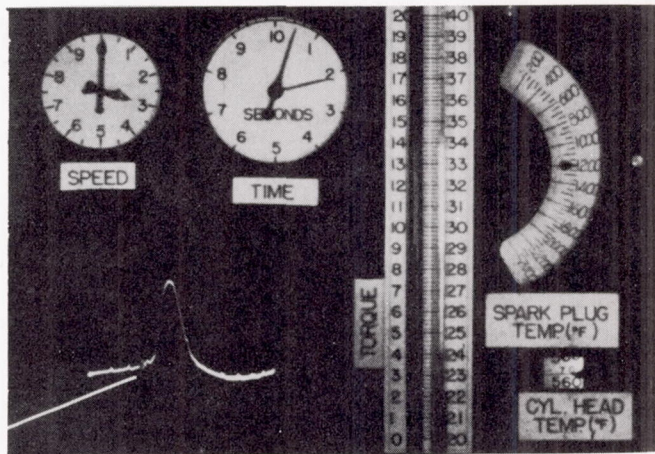
(b)   Ignition at 75° B.T.C.

Ionization-gap trace
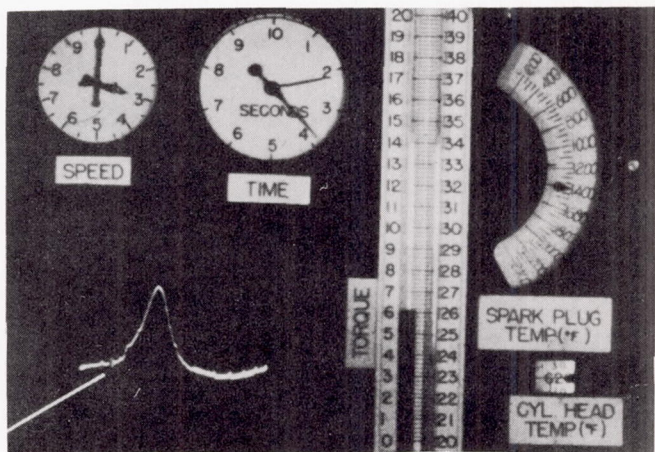
(c)   Ignition at 155° B.T.C.

Figure 3. — Prints made from motion-picture film of preig-
nition test showing instruments photographed during pre-
ignition.   Time of ignition determined from ionization-
gap trace and timing marks on pressure-time diagram.
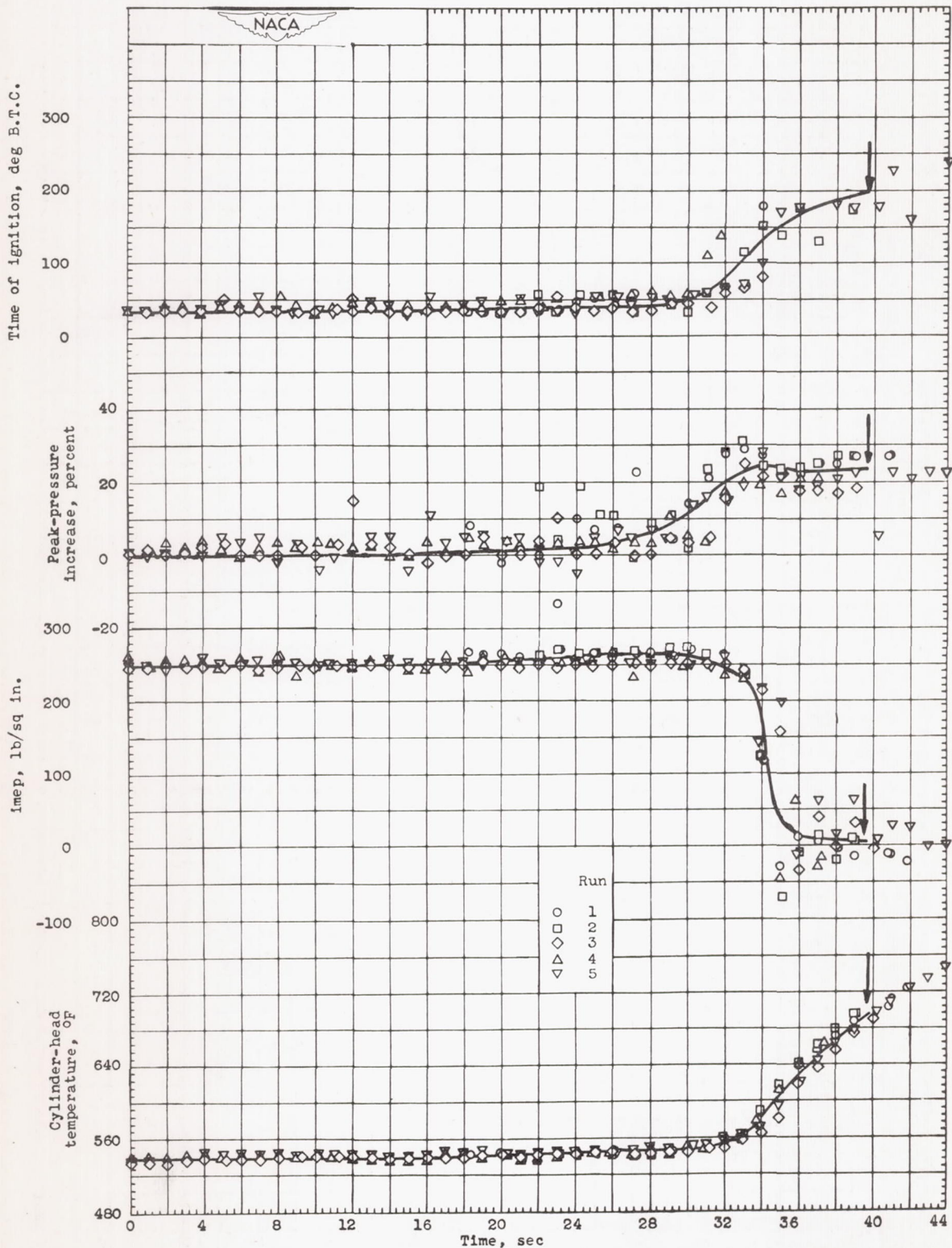
Figure 4. - Typical preignition plot showing scatter of data of five runs at approximately same engine conditions. Engine speed, 3000 rpm; spark advance: inlet, 28° B.T.C.; exhaust, 34° B.T.C.; compression ratio, 6.65; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-oil temperature, 185° F; fuel-air ratio, 0.070; fuel, 30-percent cumene blend; source of preignition, spark plug in exhaust side. (Arrows indicate time of backfire.)
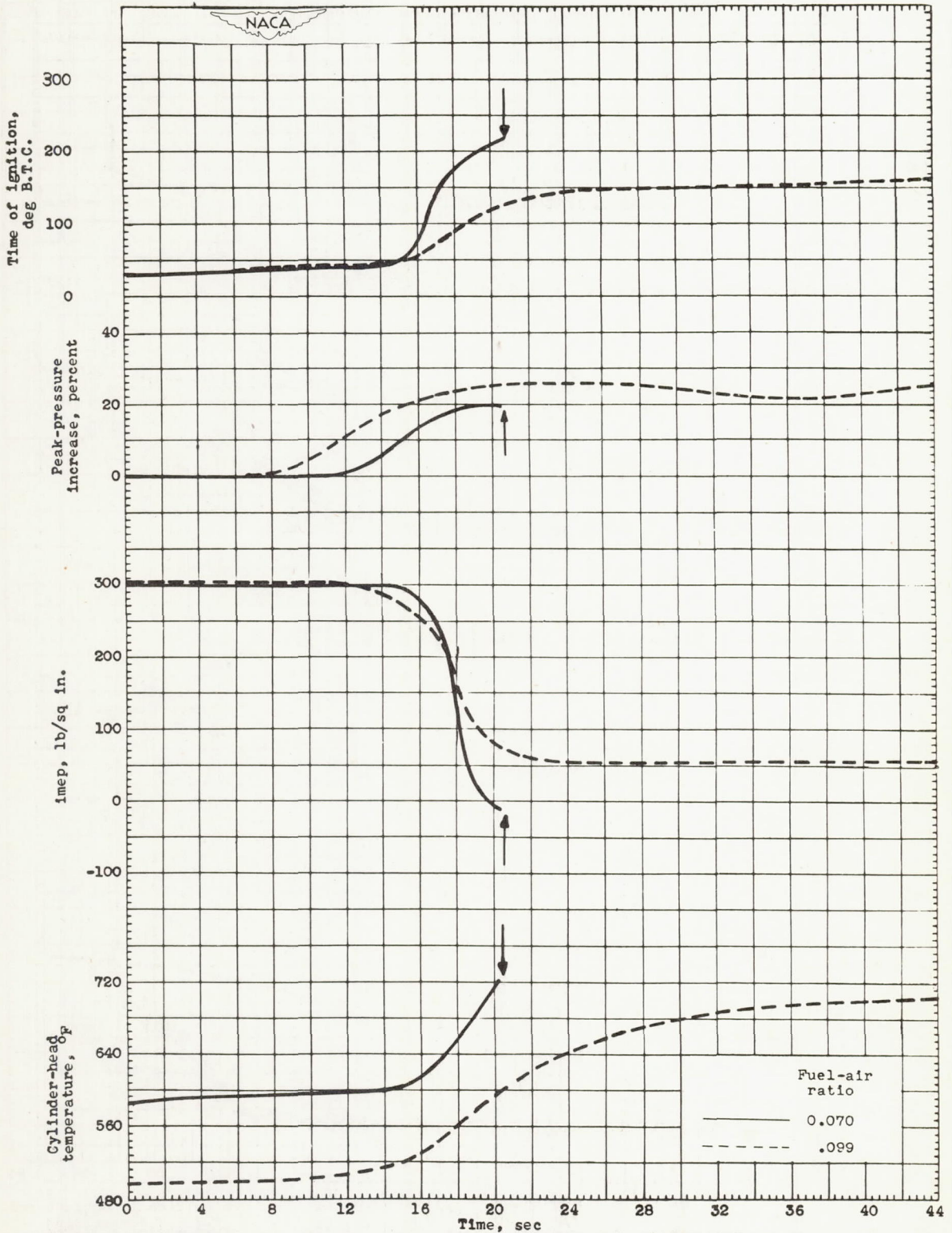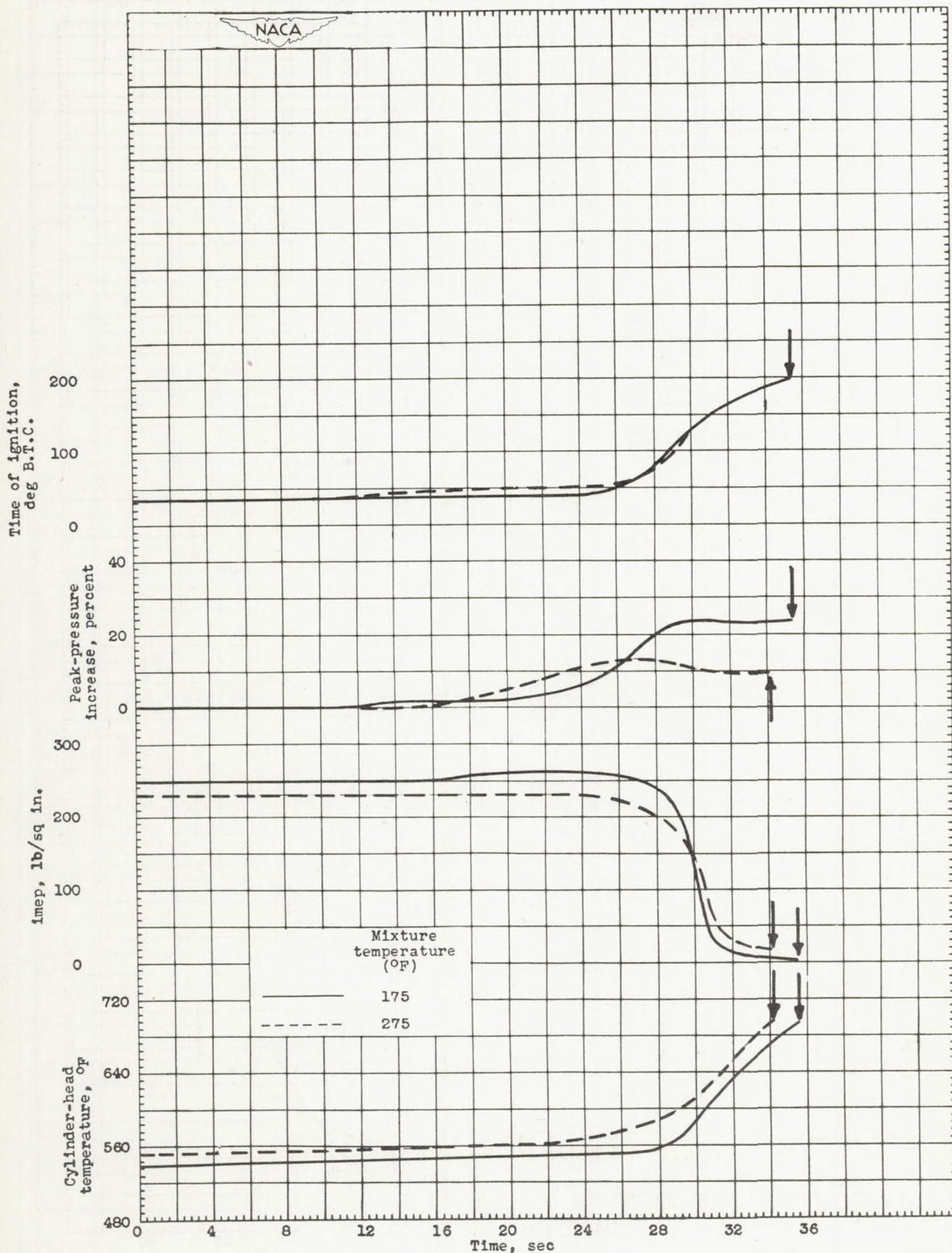
Figure 5. - Effect of fuel-air ratio on behavior of engine when preignition is encountered. Engine speed, 3000 rpm; spark advance: inlet, 28° B.T.C.; exhaust, 34° B.T.C.; compression ratio, 6.65; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-oil temperature, 185° F; fuel, 30-percent cumene blend; source of preignition, spark plug in exhaust side. (Arrows indicate time of backfire.)
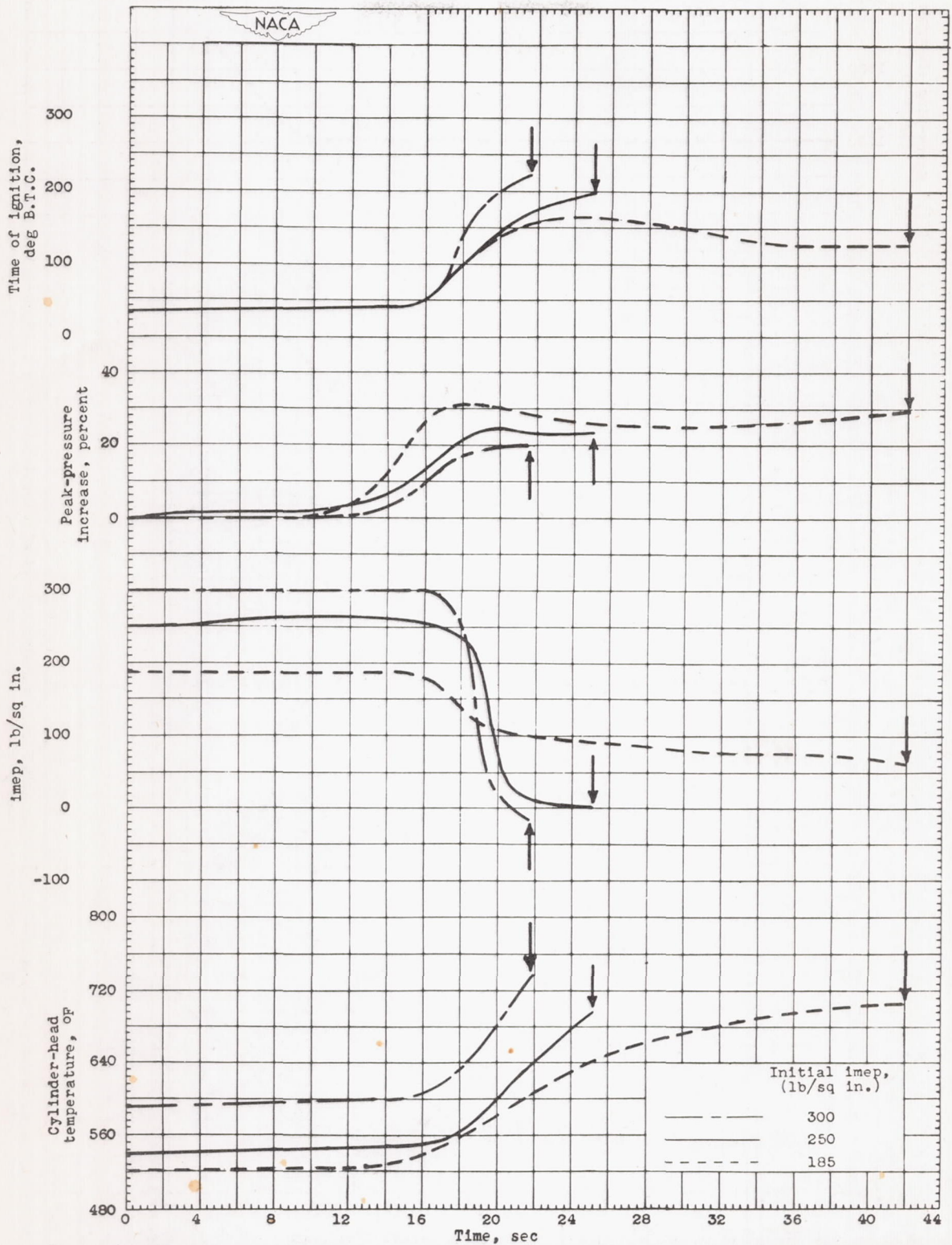
Figure 6. - Effect of initial power output on behavior of engine when preignition is encountered. Engine speed, 3000 rpm; spark advance: inlet, 28° B.T.C.; exhaust, 34° B.T.C.; compression ratio, 6.65; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-oil temperature, 185° F; fuel-air ratio, 0.070; fuel, 30-percent cumene blend; source of preignition, spark plug in exhaust side. (Arrows indicate time of backfire.)
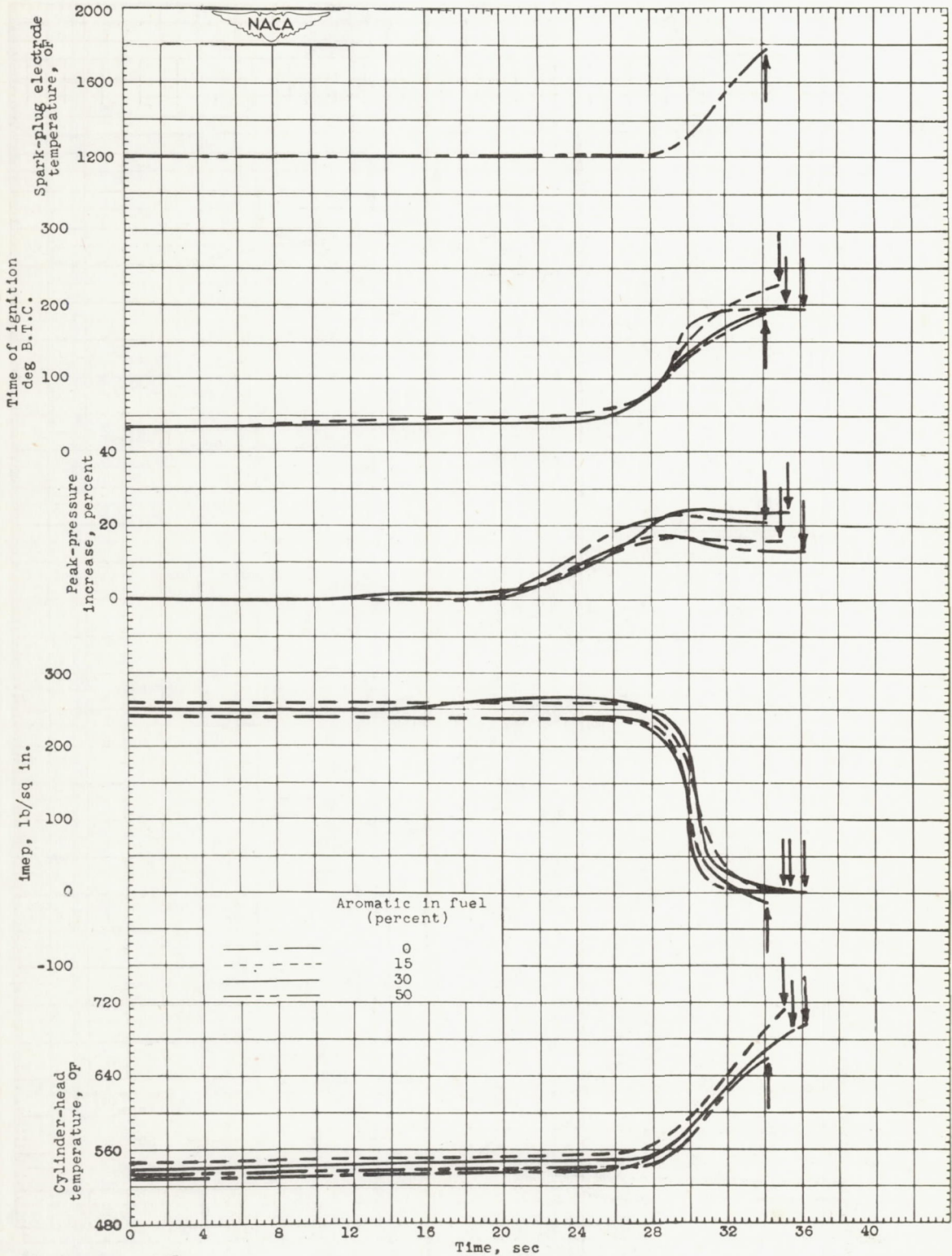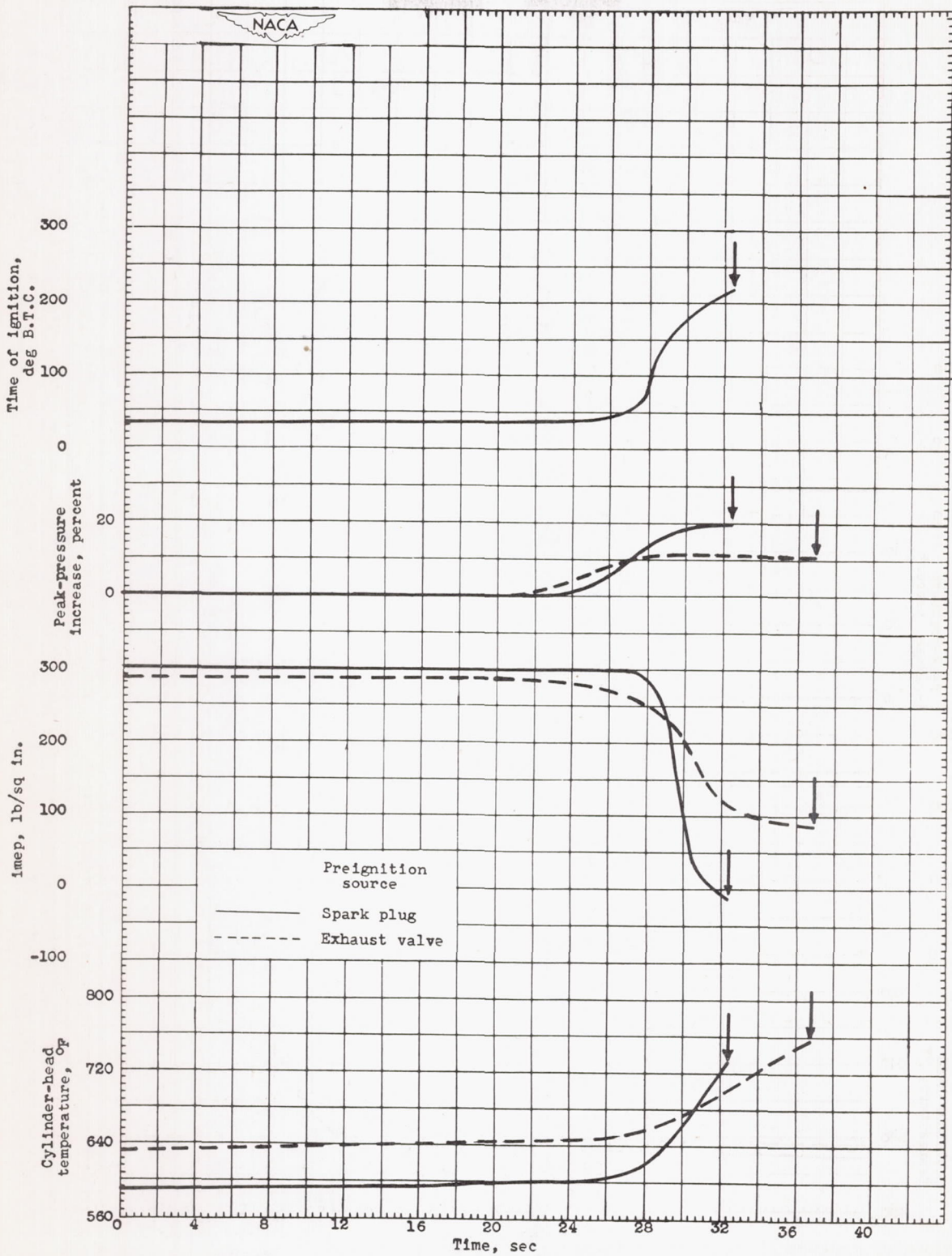
Figure 7. - Effect of aromatic content of fuels on behavior of engine after preignition is encountered. Engine speed, 3000 rpm; spark advance: inlet, 28° B.T.C.; exhaust, 34° B.T.C.; compression ratio, 6.65; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-oil temperature, 185° F; fuel-air ratio, 0.070; source of preignition, spark plug in exhaust side. (Arrows indicate time of backfire.)
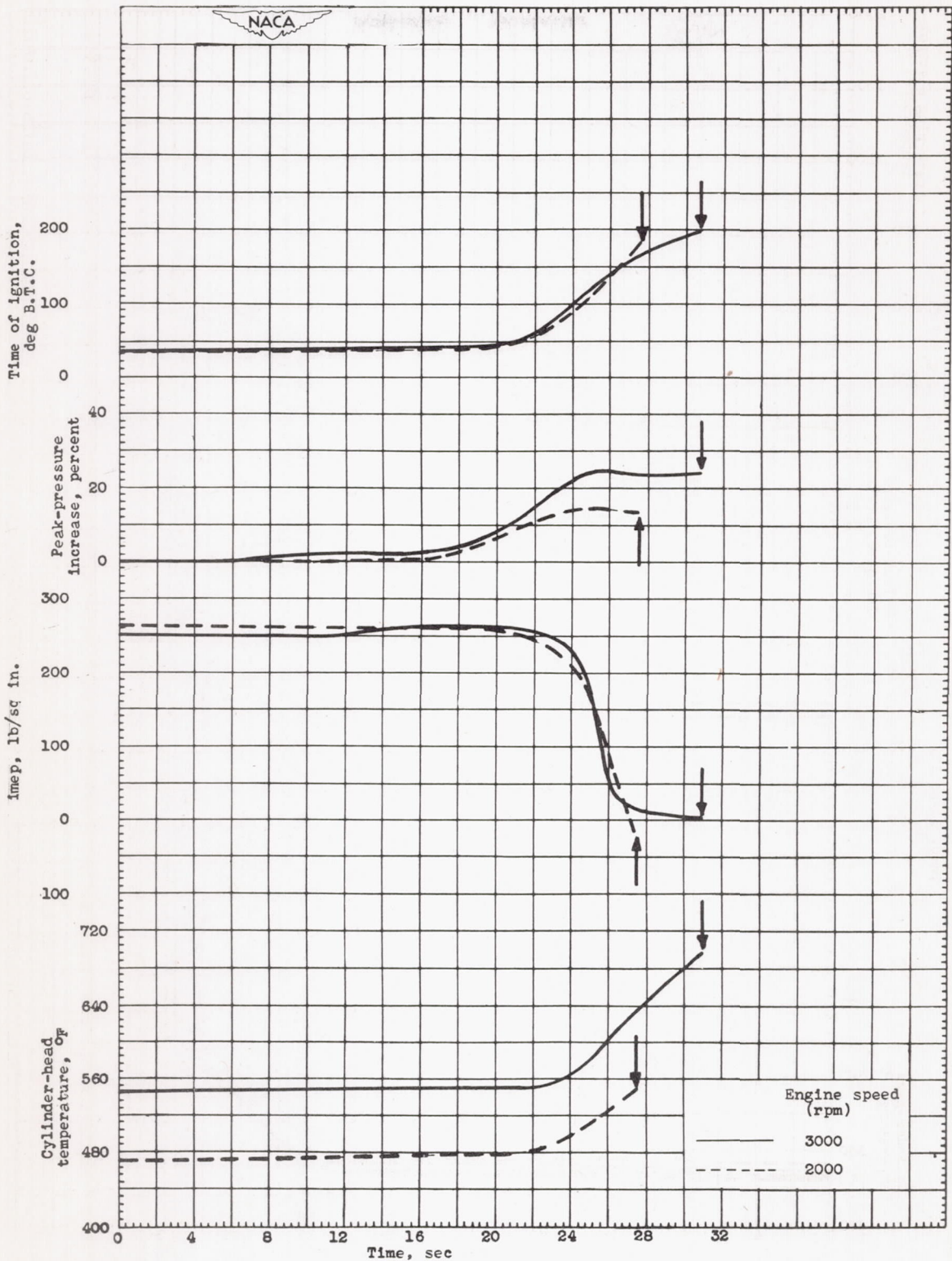
Figure 8. - Effect of engine speed on behavior of engine when preignition is encountered. Spark advance: inlet, 28° B.T.C.; exhaust, 34° B.T.C.; compression ratio, 6.65; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-oil temperature, 185° F; fuel-air ratio, 0.070; fuel, 30-percent cumene blend; source of preignition, spark plug in exhaust side. (Arrows indicate time of backfire.)

Figure 9. - Effect of mixture temperature on behavior of engine when preignition is encountered. Engine speed, 3000 rpm; spark advance: inlet, 28° B.T.C.; exhaust, 34° B.T.C.; compression ratio, 6.65; outlet-coolant temperature, 250° F; inlet-oil temperature, 185° F; fuel-air ratio, 0.070; fuel, 30-percent cumene blend; source of preignition, spark plug in exhaust side. (Arrows indicate time of backfire.)

Figure 10. - Effect of preignition source on behavior of engine when preignition is encountered. Engine speed, 3000 rpm; spark advance: inlet, 28° B.T.C.; exhaust, 34° B.T.C.; compression ratio, 6.65; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-oil temperature, 185° F; fuel-air ratio, 0.070; fuel, 30-percent cumene blend. (Arrows indicate time of backfire.)
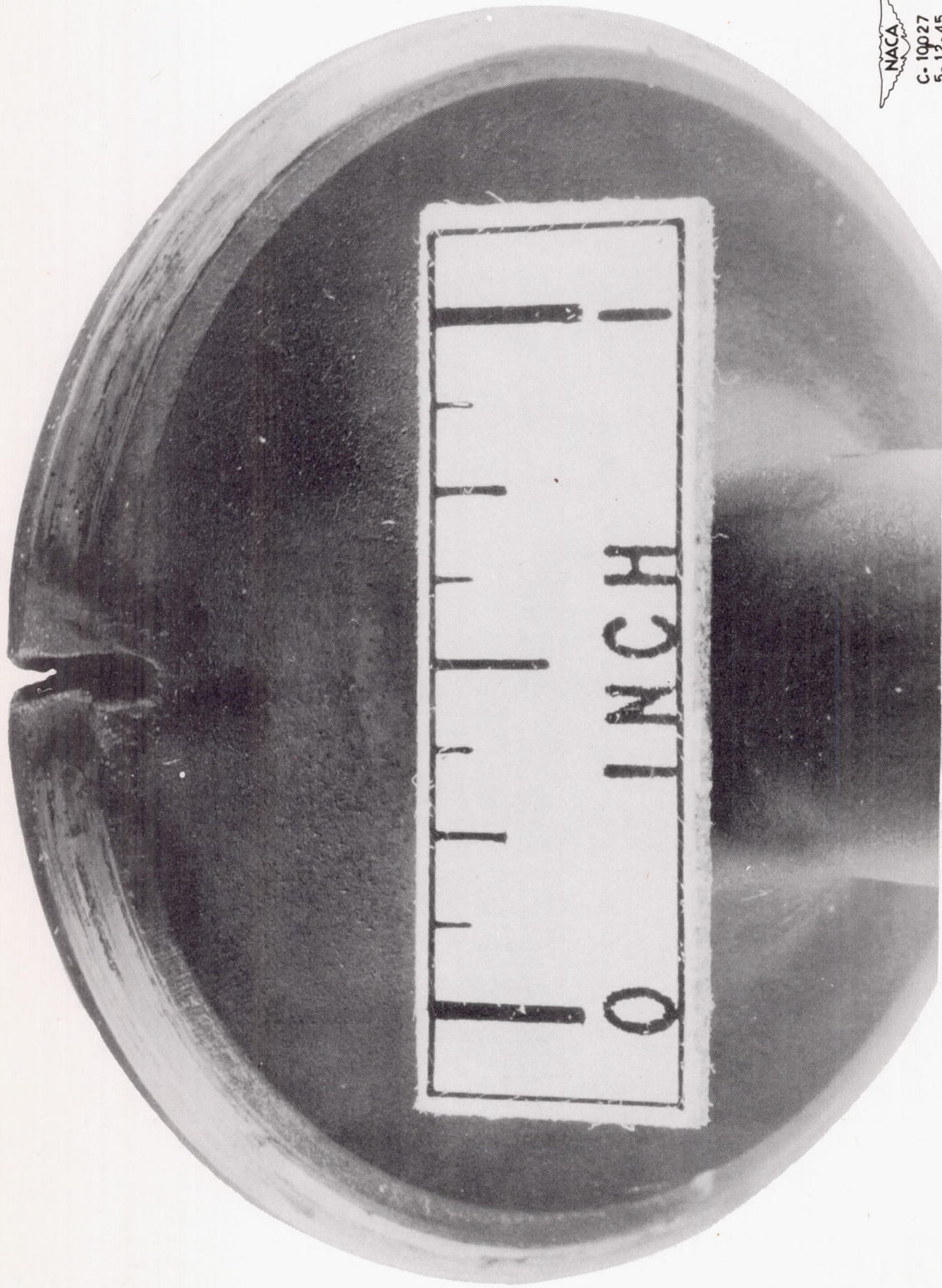
Figure 11. — Intake valve burned during preignition runs.
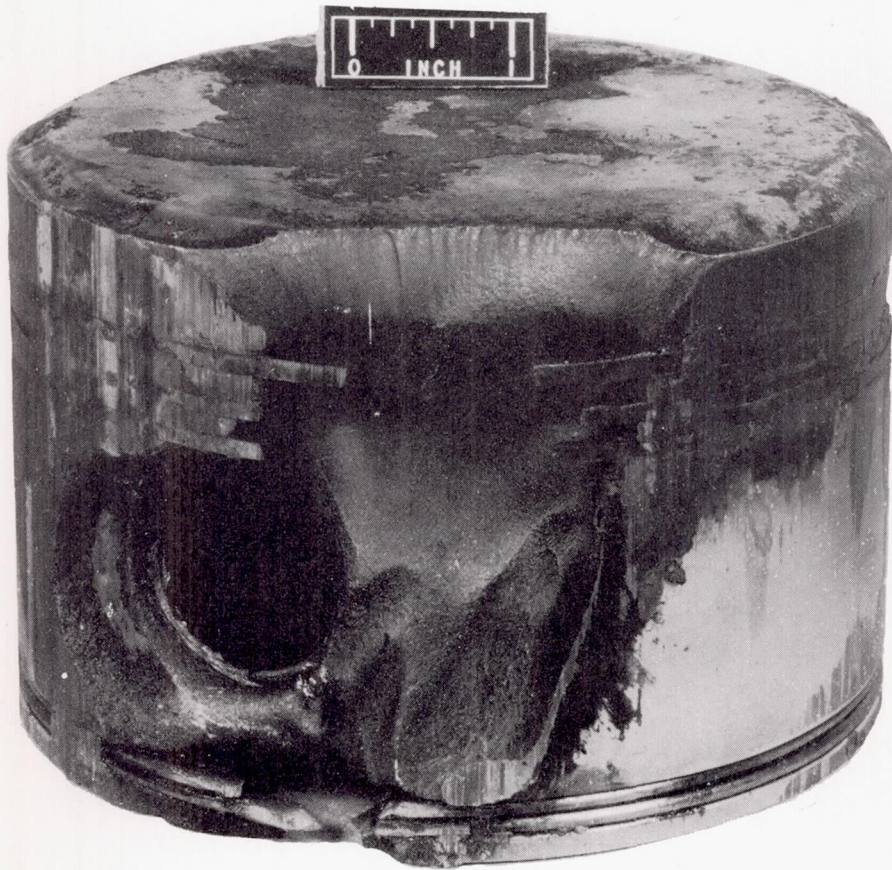
(a) Clearance, 0.004-inch less than normal; imep, 271
     pounds per square inch; fuel-air ratio, 0.098.

Figure 12. - Exhaust-side view of piston failures caused by
   preignition with various clearances between top of skirt
   and cylinder barrel.
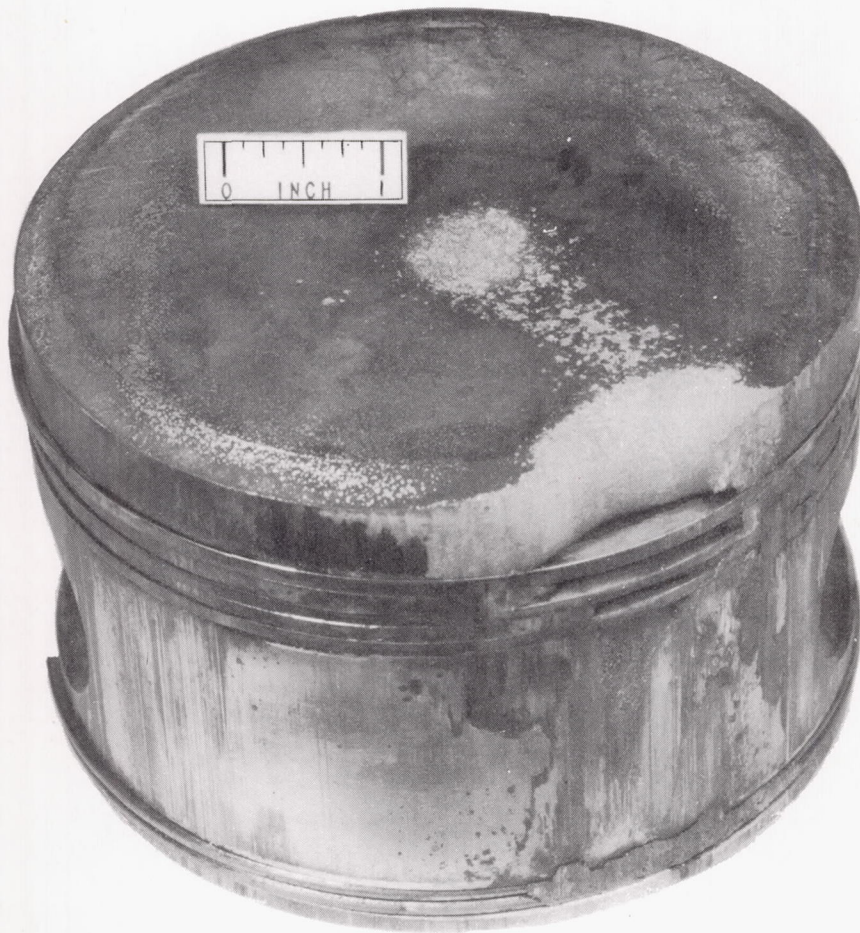
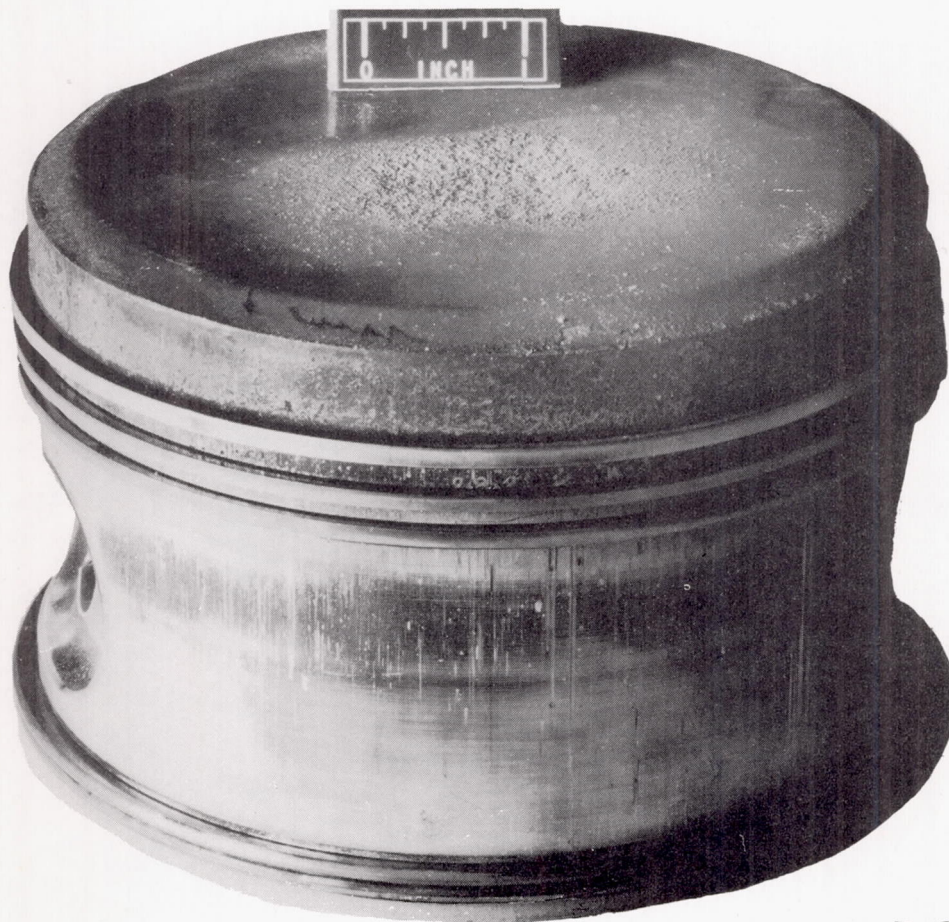(b) Clearance, normal; imep, 364 pounds per square inch;
     fuel-air ratio, 0.094.

Figure 12. – Continued. Exhaust-side view of piston failures
caused by preignition with various clearances between top
of skirt and cylinder barrel.
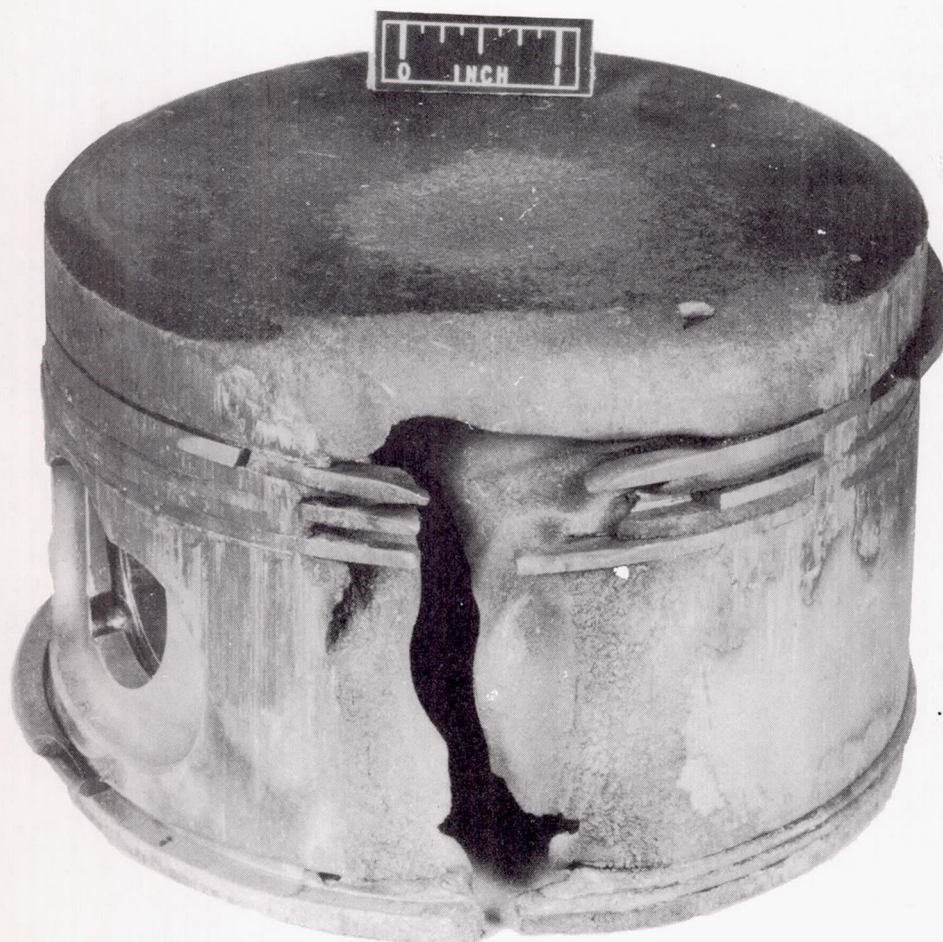
(c) Clearance, 0.005-inch greater than normal; imep, 364
     pounds per square inch; fuel-air ratio, 0.094.

Figure 12. - Continued. Exhaust-side view of piston failures
  caused by preignition with various clearances between top
  of skirt and cylinder barrel.

(d)   Clearance, 0.013-inch greater than normal; imep, 392
        pounds per square inch; fuel-air ratio, 0.092.

Figure 12. - Concluded. Exhaust-side view of piston failures
  caused by preignition with various clearances between top
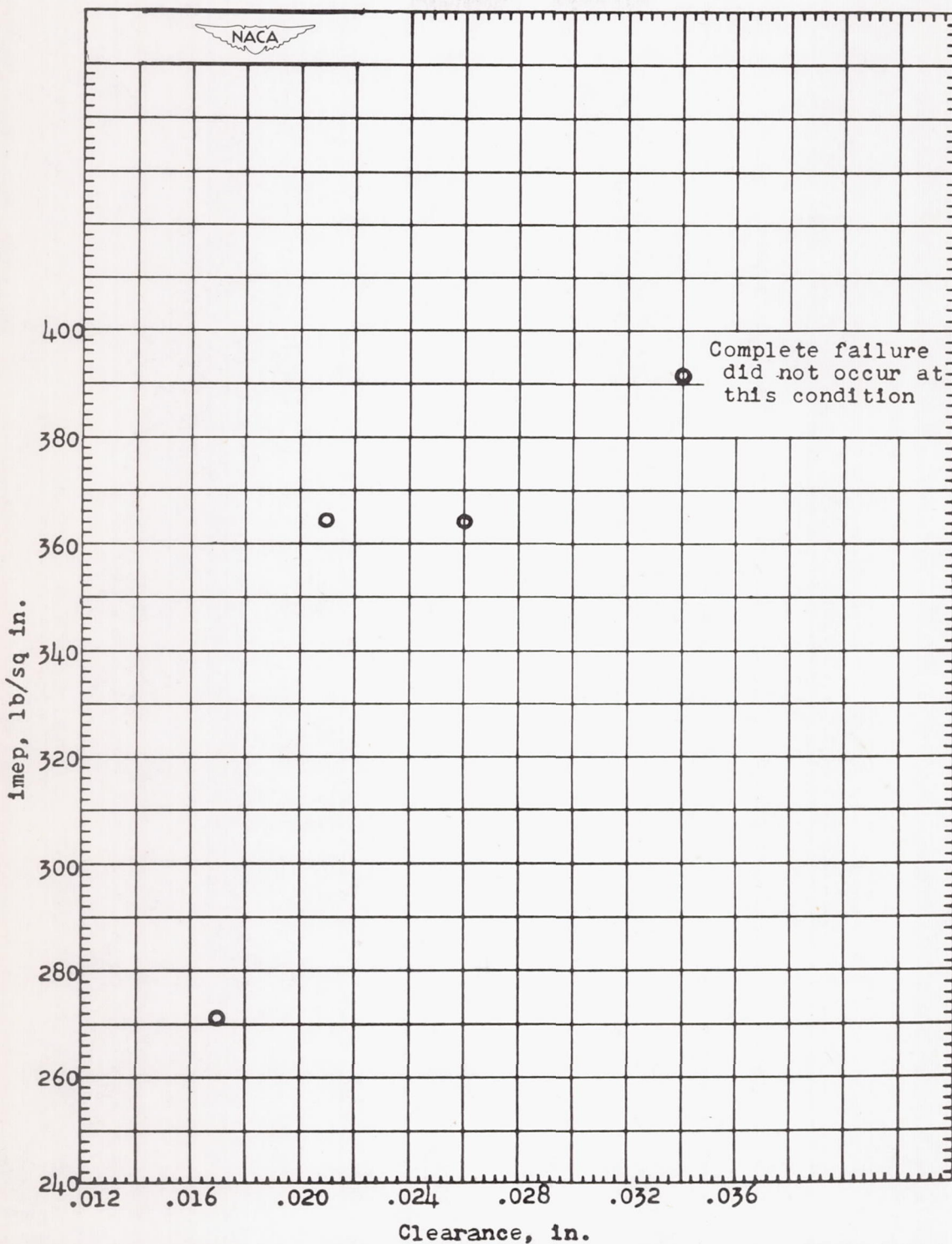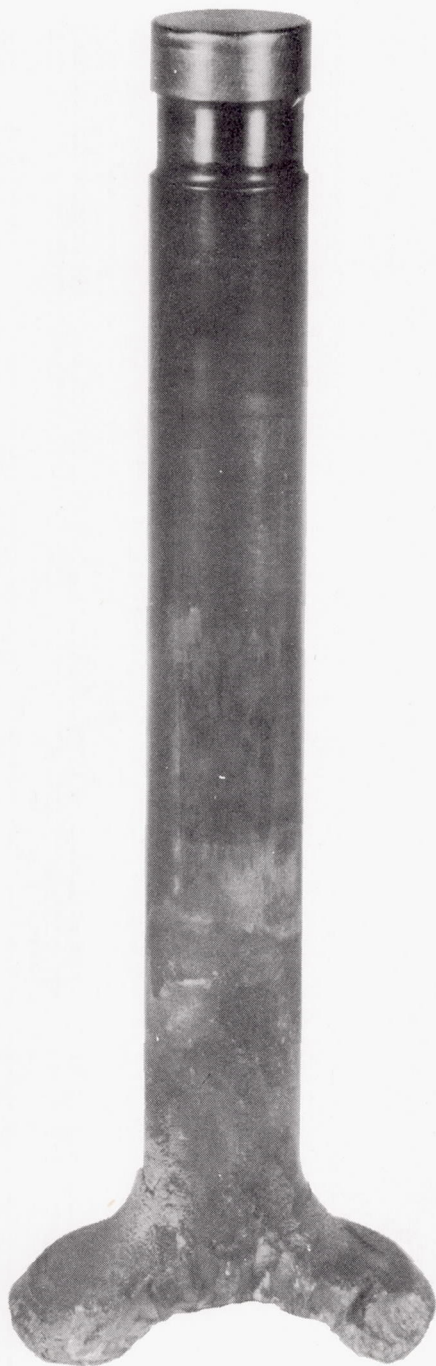 of skirt and cylinder barrel.

Figure 13.- Effect of piston clearance (measured between top of piston
   skirt and cylinder barrel) on indicated mean effective pressure
   necessary to cause piston seizure when preignition is encountered.

Figure 14. - Damage to exhaust valve accompanying piston
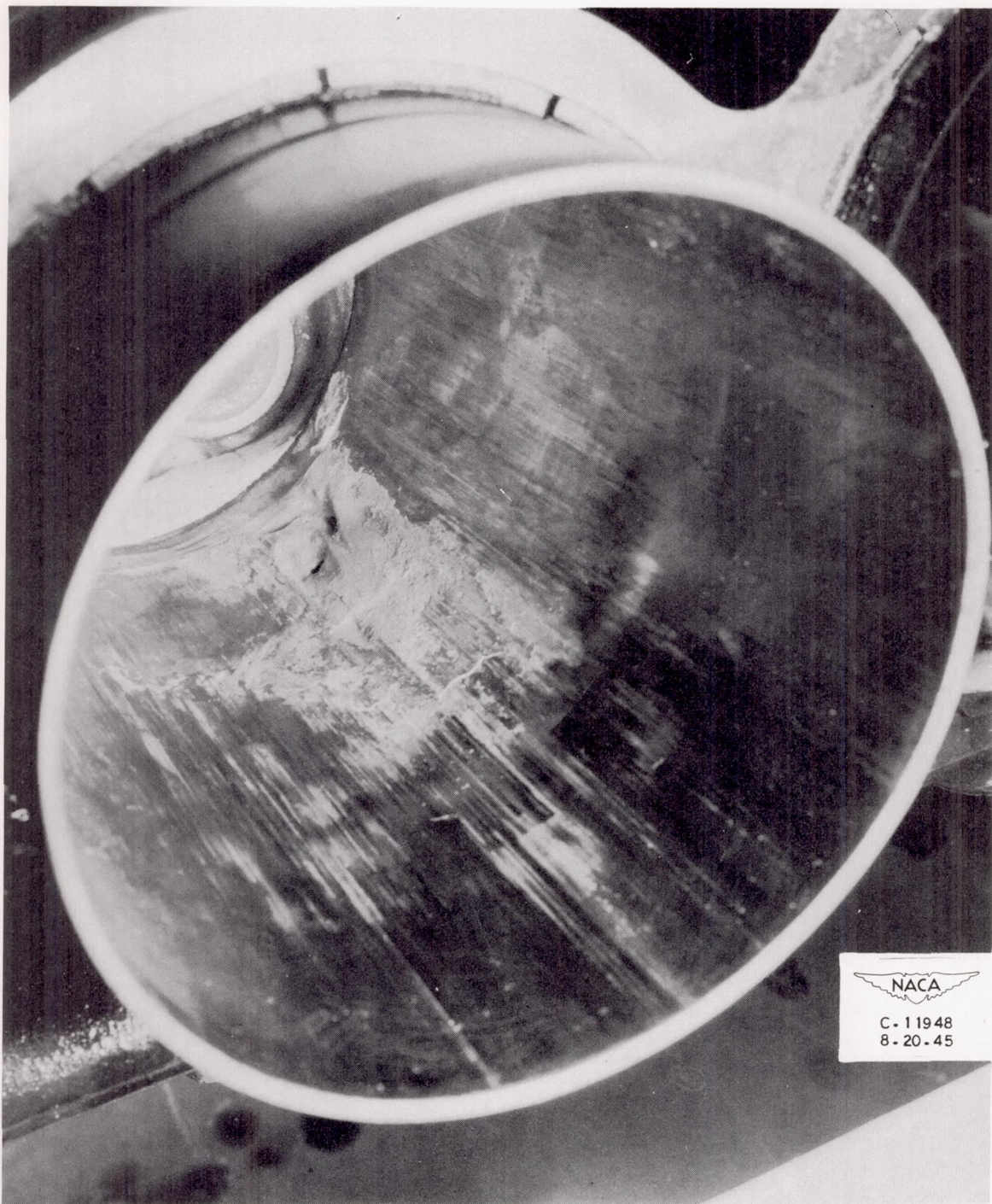failure of figure 12(b).

Figure 15. - Damage to cylinder barrel caused by piston failure of figure 12(c).