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RESEARCH MEMORANDUM

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EFFECT OF FUEL COMPOSITION, ENGINE OPERATING VARIABLES, AND SPARK-PLUG TYPE AND CONDITION ON PREIGNITION-LIMITED PERFORMANCE OF AN R-2800 CYLINDER

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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EFFECT OF FUEL COMPOSITION, ENGINE OPERATING VARIABLES AND SPARK-PLUG TYPE AND CONDITION ON PREIGNITION-LIMITED PERFORMANCE OF AN R-2800 CYLINDER

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SUMMARY

The preignition characteristics of the R-2800 cylinder, as affected by fuel composition, engine operating variables, and spark-plug type and condition, were evaluated. The effects on preignition-limited performance of various percentages of aromatics (benzene, toluene, cumene, and xylene) in a base fuel of triptane were investigated. Two paraffins (triptane and S + 6.0 ml TEL/gal) and two refinery blends (28-R and 33-R) were preignition-rated. The effect of changes in the following engine operating variables on preignition limit was determined: inlet-air temperature, rear-spark-plug-gasket temperature, engine speed, spark advance, tappet clearance, and oil consumption. Preignition limits of the R-2800 cylinder using Champion C34S and C35S and AC-LS86, LS87, and LS88 spark plugs were established and the effect of spark-plug deterioration was investigated.

No definite trends in preignition-limited indicated mean effective pressure were indicated for aromatics as a class when increased percentages of different aromatics were added to a base fuel of triptane. Three types of fuel (aromatics, paraffins, and refinery blends) showed a preignition range for this cylinder from 85 to 104 percent when based on the performance of S plus 6.0 ml TEL per gallon as 100 percent. The R-2800 cylinder is therefore relatively insensitive to fuel composition when compared to a CFR F-4 engine, which had a preignition range from 72 to 100 percent for the same fuels.

Six engine operating variables were investigated with the following results: preignition-limited indicated mean effective pressure decreased with increases in engine speed, rear-spark-plug-gasket temperature, inlet-air temperature, and spark advance beyond 20° B.T.C. and was unaffected by rate of oil consumption or by tappet clearance.

Spark plugs were rated over a range of preignition-limited indicated mean effective pressure from 200 to 390 pounds per square inch at a fuel-air ratio of 0.07 in the following order of increased resistance to preignition: AC-LS87, AC-LS88, Champion C35S, AC-LS86, and Champion C34S. Spark-plug deterioration in the form of cracks in the porcelain did not affect the preignition limit. When pieces of porcelain had been broken away from the center electrode and were retained in the spark-plug cavity, the preignition limit was decreased as much as 57 percent. When the broken pieces had been removed, the preignition limit increased from that of the undamaged porcelain as the weight of removed porcelain was increased.

INTRODUCTION

The preignition problem in aircraft engines has become more important as specific power output has increased. As knock limits have been raised through development of better fuels, in some cases, cylinder cooling has become marginal. The heat loading of cylinders is therefore rapidly reaching the limit where preignition rather than knock becomes the limiting factor.

Studies have been made using a CFR F-4 engine (references 1 and 2), a 17.6 engine (reference 3), and an O-1230 cylinder (reference 2), which have shown the preignition characteristics of various fuels in these engines when using an engine-heated hot spot. The effect of engine operating variables on the preignition-limited performance of a CFR engine (reference 4) and a 17.6 engine (reference 5) using an engine-heated hot spot have been recorded. Extensive work has also been done to establish a standard procedure for the determination of preignition ratings of aircraft spark plugs in the 17.6 engine (reference 6) and preignition ratings based on this method have been reported for many aircraft spark plugs.

The limitations of engine performance imposed by preignition resulting from an engine-heated hot spot, however, vary with the cylinder type for a given set of operating conditions because of differences in heat-transfer characteristics. The preignition rating of one cylinder type on an absolute basis with respect to fuels, spark plugs, and engine operating variables, therefore, cannot be applied to another cylinder type; each type must be individually rated. At the request of the Bureau of Aeronautics, Navy Department, the performance limitations of the R-2800 engine that are imposed by preignition and possible methods of eliminating its destructive effects were investigated at the NACA Cleveland laboratory. The preignition characteristics of this air-cooled cylinder as affected by changes in fuel, engine operating variables, spark-plug type and condition were evaluated. The effect on preignition-limited performance of various percentages of aromatics (benzene, toluene, cumene, and xylene) in a base fuel of triptane was investigated. Two paraffins (triptane and S plus 6.0 ml TEL/gal) and two refinery blends (28-R and 33-R) were preignition-rated. The effect of changes in the following engine operating variables on preignition limit was determined: inlet-air temperature, rear-spark-plug-gasket temperature, engine speed, spark advance, tappet clearance, and oil consumption. Preignition limits of the R-2800 cylinder using Champion C34S and C35S and AC-LS86, LS87, and LS88 spark plugs were established and the effect of spark-plug deterioration was investigated.

APPARATUS

An R-2800-69 cylinder was mounted on a CUE crankcase and standard engine baffles were fitted to the cylinder. At the beginning of the investigation, difficulty was experienced with burned pistons (fig. 1) and fractured exhaust valves (fig. 2). Piston burning was eliminated by increasing the side clearance between the piston and the cylinder barrel 0.006 inch on the diameter. The exhaust-valve fractures occurred at the neck of the valve during engine operation at a rear-spark-plug-gasket temperature of 550° F and engine speed of 2600 rpm. These fractures were eliminated by installing a high-speed valve-gear assembly, which indicates that the exhaust valves had probably failed as a result of fatigue induced by a combination of high operating temperature and an exhaust-valve gear not suitable for high-speed operation.

The rear-spark-plug-gasket thermocouple was connected to an automatic potentiometer-type regulator, which controlled the cooling-air flow to maintain a constant gasket temperature. All other operating temperatures were measured with iron-constantan thermocouples and a self-balancing potentiometer. The combustion-air system consisted of a pressure-regulating valve, an orifice to measure the air flow, an air-heater unit, a surge tank, and a vaporization tank. The inlet-air temperature was measured by a thermocouple placed at the outlet of the surge tank. Fuel was injected through a spring-loaded injection nozzle located in the top of the vaporization tank. The fuel flow was measured by calibrated rotameters.

Preignition was detected by means of a magnetostriction-type pickup unit used with a cathode-ray oscilloscope. An AC-LS87 spark plug was used as the engine-heated hot spot (except when different spark plugs were being rated) and was located in the rear spark-plug hole. The use of this spark plug as the hot spot was considered satisfactory because it was durable, gave reproducible results and was convenient to install.

Combustion-gas leakage through damaged AC-LS87 spark plugs was determined by sealing the spark-plug connector elbow, connecting the elbow to an inverted cylindrical graduate, and measuring the rate of gas leakage by timed water displacement.

Triptane plus 4.0 ml TEL per gallon was chosen as the base fuel for this investigation because it has a preignition limit very close to that of 28-R, a representative aviation fuel. The knock limit of the base fuel was high enough to assure that no runs would be limited by knock before preignition was encountered.

Data for fuels used in this program are listed in the following table:

Fuel	Tetraethyl lead (ml/gal)	Aromatic (percent)	Remarks
Benzene	4.0	100	1° C distillation range
Toluene	4.0	100	1° C distillation range
Cumene	4.0	100	Atlantic Refinery grade
Xylene	4.0	100	3° C distillation range, mixture of orthoxylene, metaxylene, and paraxylenes
S	6.0	0	- - - - - - - - - - - - - -
Triptane	4.0	0	1° C distillation range from 5- to 90-percent point
28-R	4.5	10.1	Aromatic is all cumene
33-R	4.5	8.3	Aromatic is 23 percent cumene

All aromatic fuel blends in triptane were mixed on a volume basis and contained 4.0 ml TEL per gallon.

INVESTIGATION CONDITIONS AND PROCEDURE

The fixed engine operating conditions, except as each was investigated as the primary variable, were:

Compression ratio	6.75
Engine speed, rpm	2600
Inlet-air temperature, °F	260
Spark advance, both plugs, °B.T.C.	20
Oil-inlet temperature, °F	185
Rear-spark-plug-gasket temperature, °F	425
Tappet clearance, inch	
Intake	0.025
Exhaust	0.015
Oil consumption, pound per horsepower-hour	approx. 0.01 (standard ring assembly)

Preignition-limited mixture-response curves for points at rich mixtures were obtained by setting the fuel flow and increasing the manifold pressure until cycles of early ignition were regularly encountered. The manifold pressure was then reduced slightly, until early ignition was only occasionally indicated on the oscilloscope trace and the cylinder cooling-air pressure drop remained steady. A continuous increase in cooling-air pressure drop without a change in engine operating conditions indicated an increase in cylinder temperatures resulting from more frequent cycles of early ignition and, therefore, indicated run-away preignition. Points at lean mixtures were obtained in the same manner except that the manifold pressure was set and the fuel flow increased to the preignition point. At a speed of 2600 rpm the point of incipient preignition was sharply defined while at lower engine speeds, this point was not as definite.

RESULTS AND DISCUSSION

Fuel composition. - The preignition-limited performance of an R-2800 cylinder as affected by various aromatic blends of benzene, toluene, cumene, and xylene in a base fuel of triptane is shown in figure 3. The data for the different fuel blends are plotted with the ratio of actual to stoichiometric fuel-air ratios for each blend as the abscissa to place them on a comparable basis. In order to compensate for small differences in the various AC-LS87 spark plugs used as hot spots and for engine deterioration, check points on triptane plus 4.0 ml TEL per gallon were taken at a fuel-air ratio of 0.08 at the beginning and end of each run. These check points were then corrected to the basic indicated mean effective pressure of 225 pounds per square inch at a fuel-air ratio of 0.08; the fuel-blend data for that run were also corrected by the same amount. The average correction was about 5 pounds per square inch and the maximum was 15 pounds per square inch. All other data presented, however, were not corrected for the hot-spot variation.

The data of figure 4 indicate no common trend for aromatics as a class in the preignition-limited performance of the cylinder obtainable with various percentages of aromatics in the base fuel. The greatest reduction in the preignition-limited indicated mean effective pressure is obtained with the addition of benzene. If more than 60 percent of benzene is added to the base fuel, however, the preignition limit again increases slightly. Toluene shows no appreciable effect on the preignition rating of the cylinder until 75 percent is added to the base fuel; further addition of toluene increases the preignition limit sharply until at 100-percent toluene the preignition-limited indicated mean effective pressure is about 45 pounds per square inch above that obtained with 100-percent triptane. Cumene was the only aromatic investigated for which preignition-limited indicated mean effective pressure is inversely proportional to aromatic content. Pure cumene, however, lowers the preignition-limited indicated mean effective pressure only 20 pounds per square inch below that obtained with the base fuel. Xylene shows the smallest effect on the preignition rating of the cylinder.

The preignition limits of the four aromatics are compared with those of triptane, S plus 6.0 ml TEL per gallon, and 33-R in figure 5. Although 28-R could not be used at these conditions without knock, preliminary work showed that its preignition rating in the R-2800 cylinder is very slightly above that of triptane plus 4.0 ml TEL per gallon. The data representing the performance of 28-R fuel are therefore plotted by application of this correlation to data obtained with triptane plus 4.0 ml TEL per gallon. The preignition limits of the cylinder at two percentages of stoichiometric mixture and at one fuel-air ratio for four aromatics, two paraffins, and two refinery blends are presented in table I.

In order to compare the preignition rating of these fuels in the R-2800 cylinder with their performance in several other cylinders, table II has been compiled. Table III lists the engine operating conditions at which the data of table II were obtained. The ratings for fuels in the R-2800 cylinder are relative to S plus 6.0 ml TEL per gallon whereas in the O-1230 cylinder and the CFR F-4 engine the ratings are relative to S plus 4.0 ml TEL per gallon. Because the data of reference 2 indicate very little difference between the preignition ratings of S plus 4.0 ml TEL per gallon and S plus 6.0 ml TEL per gallon, the difference in reference fuel has little effect on the comparison among engines. The preignition-limited performance of the R-2800 cylinder is less sensitive to the type of fuel used than are the O-1230 cylinder and the CFR F-4 engine. All of the fuels except toluene are in the same relative positions when rated in the several engines.

Engine operating variables. - In order to aid in the evaluation of the preignition characteristics of the R-2800 cylinder, the effects of engine operating variables on preignition-limited performance were investigated.

A linear relation exists between inlet-air temperature and preignition-limited power (fig. 6(a)). For each 100° F increase in inlet-air temperature, the preignition-limited indicated mean effective pressure decreased 20 pounds per square inch. The preignition-limited inlet-air pressure increased very slightly with increasing inlet-air temperature.

A linear relation also exists between rear-spark-plug-gasket temperature and preignition-limited power (fig. 6(b)). In this case, each 100° F increase in cylinder temperature decreased the preignition-limited indicated mean effective pressure 30 pounds per square inch.

When engine speed was changed, each increase of 100 rpm lowered the preignition-limited indicated mean effective pressure 6.5 pounds per square inch over the range covered (fig. 6(c)). Preignition-limited indicated horsepower, however, increased with increase in engine speed.

Preignition-limited indicated mean effective pressure changed very little when the spark was advanced from 0° to 20° B.T.C. (fig. 6(d)). Further advance of the spark decreased the preignition-limited indicated mean effective pressure 30 pounds per square inch for each 10° increase in spark advance.

In order to investigate the effect of residual gases on the preignition limit, the tappet-clearance cold setting was varied from 0 to 0.062 inch; the same clearance was used for the intake and the exhaust valves during each run. The resulting change in valve overlap had no effect on the preignition limit (fig. 6(e)).

The rate of oil consumption was changed to determine its effect on the preignition limit. Specific oil consumption at preignition-power level was measured first with the standard ring assembly and then with the oil-scraper and two oil-control rings removed. No change in preignition limit resulted from increased oil consumption (fig. 6(f)). It is interesting to note that, after 100 hours of operation under incipient preignition at normal engine operating conditions for this program (which included some advanced preignition while determining data points), the standard ring assembly still held the indicated specific oil consumption below 0.01 pound per horsepower-hour.

Many of the engine operating variables investigated in the R-2800 cylinder have been evaluated in the 17.6 engine (reference 5) and the F-4 engine (reference 1). Trends in the 17.6 engine were similar to those observed herein except that no appreciable change in preignition limit was noted for changes in jacket temperature; in general, the ranges covered in reference 5 were small. The F-4 engine also showed trends comparable to those of the R-2800 cylinder, except that no appreciable change in preignition limit accompanied engine speed changes and the spark-advance curve did not level off.

Spark-plug type and condition. - The types of spark plug chosen for preignition rating in the R-2800 cylinder were Champion C34S and C35S and AC-LS86, which are approved types for this cylinder; the cylinder was also rated with AC-LS87 and AC-LS88 spark plugs. The preignition-limited performance of these five spark plugs at a rear-spark-plug-gasket temperature of 550° F is shown in figure 7. Only the AC-LS87 and the AC-LS88 spark plugs could be rated at a rear-spark-plug-gasket temperature of 425° F because of limited cooling-air supply. The preignition ratings of the spark plugs in the R-2800 cylinder are compared in table IV with previously unpublished results obtained with a 17.6 engine. The spark plugs are rated in the same order in both cylinders except that the positions of Champion C34S and AC-LS86 spark plugs are reversed. The ratings of these two plugs, however, are approximately equal in both engines and variations in preignition limit of spark plugs of the same type could easily account for this discrepancy.

Because the preignition limits of new spark plugs are above that of the normal operating range, when a representative aviation fuel is used, the occurrence of preignition in service engines is due either to knock-induced preignition or deterioration of combustion-chamber parts. The engine parts that most commonly deteriorate and cause preignition are the spark plugs. Figure 8 shows that porcelain broken away from the center electrode of an AC-LS87 spark plug but retained in the spark-plug cavity reduced the preignition-limited indicated mean effective pressure as much as 57 percent. Cracking of the porcelain did not affect the preignition limit (crack not visible on reproduced photograph of fig. 8) but when the porcelain became chipped and shattered and separated from the center electrode, the preignition-limited indicated mean effective pressure of the cylinder dropped sharply. The data of figure 8 represent runs on two AC-LS87 spark plugs. During these runs the maximum rate of gas leakage during engine operation was 2.0 cubic centimeters per minute. Reference 7, however, indicates that, if the center electrode insulation deteriorates in such a way that excessive gas leakage results (about 65 cc/min), the crack will cause an increase in the center electrode temperature of about 100° F with the result that the preignition limit will be lowered.

A further investigation was made to determine the effect on preignition limit of complete removal of the bits of broken porcelain. The preignition limit of the spark plug increased in proportion to the weight of porcelain removed (fig. 9). The porcelain is evidently the source of preignition in the spark plug and removal of part of it shortens the heat-flow path. The remaining portion of porcelain is therefore cooler at the same power level. Inasmuch as the data for figures 8 and 9 required disassembly and reassembly of the spark plug, the effect of this disassembly on preignition limit was investigated and found to be within the limits of reproducibility of the preignition data.

Reproducibility of preignition data. - The preignition limits of three AC-LS87 spark plugs were checked several times to establish the reproducibility of determination of the preignition limit of any one plug. An average variation in indicated mean effective pressure of 6 pounds per square inch was observed (fig. 10), which compared favorably with the reproducibility of knock-limit data.

Of further interest is the range of preignition limits encountered with spark plugs of one type. The preignition limits of 11 new AC-LS87 spark plugs selected at random from a large stock and used as engine-heated hot spots fall within a range of indicated mean effective pressure of 30 pounds per square inch (fig. 11). Four spark plugs that had been used and reconditioned several times were investigated; the maximum variation in observed preignition-limited indicated mean effective pressure was 22 pounds per square inch (fig. 11). The preignition limits for the four used plugs, however, were higher than the highest observed preignition limit of the new plugs of the same type.

In order to determine the reason for this higher level, several new AC-LS87 spark plugs were sand-blasted several times and the preignition limit determined after each sanding. Although no definite increases were noted after successive reconditionings, the general trend of repeated sanding was to increase the preignition limit. Another interesting phenomenon observed during these runs, which would account for the higher preignition level of the four reconditioned plugs of figure 11, was the sudden increase of about 20 pounds per square inch indicated mean effective pressure in the preignition limit of new AC-LS87 spark plugs that occurred after the spark plugs had been in operation for an hour or two. The reason for this sudden increase in the preignition limit is not known.

It is therefore possible that either because the spark plugs were sanded several times or because they had been run an hour or more could account for the higher preignition limit of the reconditioned spark plugs.

SUMMARY OF RESULTS

The preignition characteristics of the R-2800 cylinder as affected by fuel composition, engine operating variables, and spark-plug type and condition can be summarized as follows:

1. Increased percentages of various aromatics added to triptane, the base fuel, showed no common trend in the preignition-limited indicated mean effective pressure for aromatics as a class. Benzene and cumene additions lowered the preignition-limited indicated mean effective pressure with benzene giving the greater reduction. Xylene additions did not affect the preignition-limited indicated mean effective pressure whereas toluene additions in large percentages increased the preignition-limited indicated mean effective pressure.

2. Three types of fuel (aromatics, paraffins, and refinery blends) showed a preignition range for this cylinder from 85 to 104 percent when based on the performance of S plus 6.0 ml TEL per gallon as 100 percent. The R-2800 cylinder is therefore relatively insensitive to fuel composition when compared to CFR F-4 engine, which had a preignition range from 72 to 100 percent for the same fuels.

3. Preignition-limited indicated mean effective pressure decreased with increases in engine speed, rear-spark-plug-gasket temperature, inlet-air temperature, spark advance beyond 20° B.T.C., and was unaffected by changes in oil consumption and in tappet clearance.

4. When the engine was operated with a fuel having preignition characteristics similar to those of aviation fuels, spark plugs, covering a range of preignition-limited indicated mean effective pressure from 198 to 390 psi at a fuel-air ratio of 0.07 were rated in the following order of increasing resistance to preignition: AC-LS87, AC-LS88, Champion C35S, AC-LS86, and Champion C34S.

5. Spark-plug deterioration in the form of cracks in the porcelain did not affect the preignition limit. If pieces of porcelain were broken away from the center electrode and retained in the spark-plug cavity, the preignition limit was lowered as much as 57 percent. If the broken pieces were removed, however, the preignition limit increased above the original limit as the weight of porcelain removed was increased.

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TABLE I - PREIGNITION-LIMITED IMEP OBTAINED WITH

VARIOUS FUELS IN R-2800 CYLINDER

Fuel	Preignition-limited imep (lb/sq in.)		
	Ratios of actual to stoichiometric fuel-air ratios, percent		Fuel-air ratio of 0.08
	110	145	
Cumene	204	236	206
Benzene	204	249	206
Triptane	217	268	224
28-R	217	270	224
33-R	226	270	230
Xylene	218	276	224
S + 6.0 ml TEL/gal	238	292	243
Toluene	254	320	254

TABLE II - PREIGNITION-LIMITED IMEP OBTAINED WITH

VARIOUS FUELS IN THREE TYPES OF CYLINDER

Fuel	Reference preignition-limited imep at fuel-air ratio of 0.08 (percent)		
	R-2800 cylinder (a)	O-1230 cylinder (b)	F-4 engine (b)
S + 4.0 ml TEL/gal	----------	100	100
S + 6.0 ml TEL/gal	100	----------	----------
Benzene	85	----------	74
Toluene	104	----------	99
Cumene	85	69	72
Xylene	92	----------	98
28-R	92	----------	87
Triptane	92	----------	----------

[a]Reference preignition-limited imep is that obtained with S + 6.0 ml TEL/gal.

[b]Reference preignition-limited imep is that obtained with S + 4.0 ml TEL/gal. (Reference 2)

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TABLE III - OPERATING CONDITIONS AT WHICH PREIGNITION LIMITS WERE OBTAINED IN THREE TYPES OF CYLINDERS

Cylinder	Operating conditions				
	Engine speed (rpm)	Compression ratio	Spark advance (°B.T.C.)	Inlet-air temperature (°F)	Cylinder temperature (°F)
R-2800	2600	6.75	20	260	[a]425
[c]O-1230	2680	6.5	30	175	[b]250
[c]F-4	1800	6.0	45	225	[b]375

[a]Rear-spark-plug-gasket temperature.
[b]Coolant-in temperature.
[c]Reference 2.

TABLE IV - PREIGNITION-LIMITED IMEP OBTAINED WITH VARIOUS SPARK PLUGS IN R-2800 CYLINDER

Spark plug	Preignition-limited imep (lb/sq in.)	
	R-2800 cylinder at fuel-air ratio of 0.07	17.6 engine at maximum thermal-plug temperature (a)
AC-LS87	198	200
AC-LS88	252	240
Champion C35S	312	254
AC-LS86	384	330
Champion C34S	390	320

[a]Average ratings.

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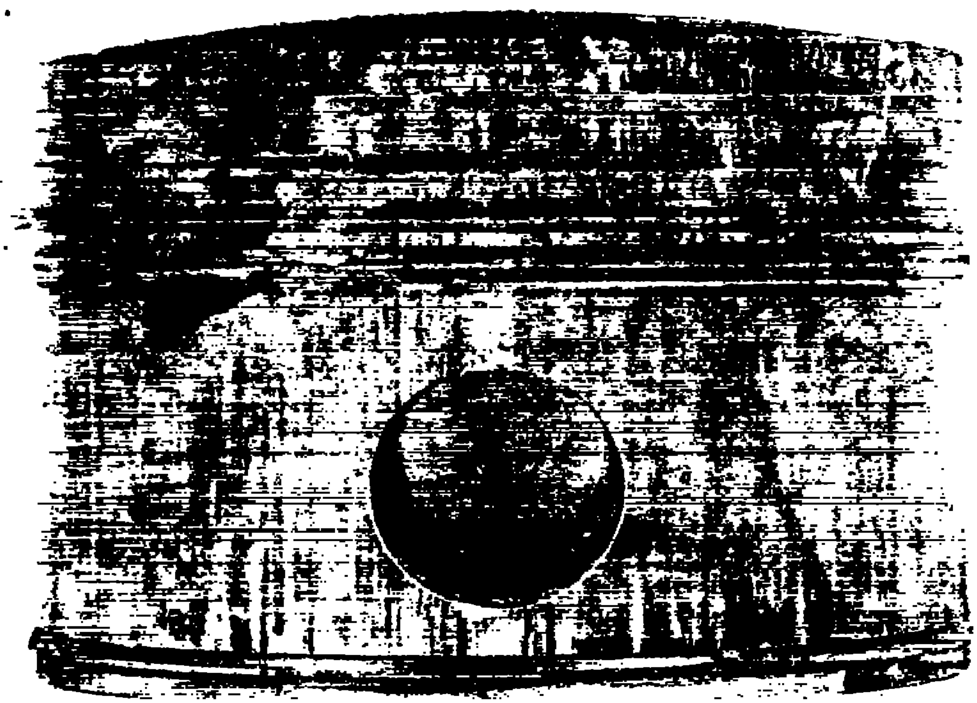

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Figure 1. - Burned piston resulting from engine operation under preignition conditions. Rear-spark-plug-gasket temperature, 550° F; standard piston clearances.

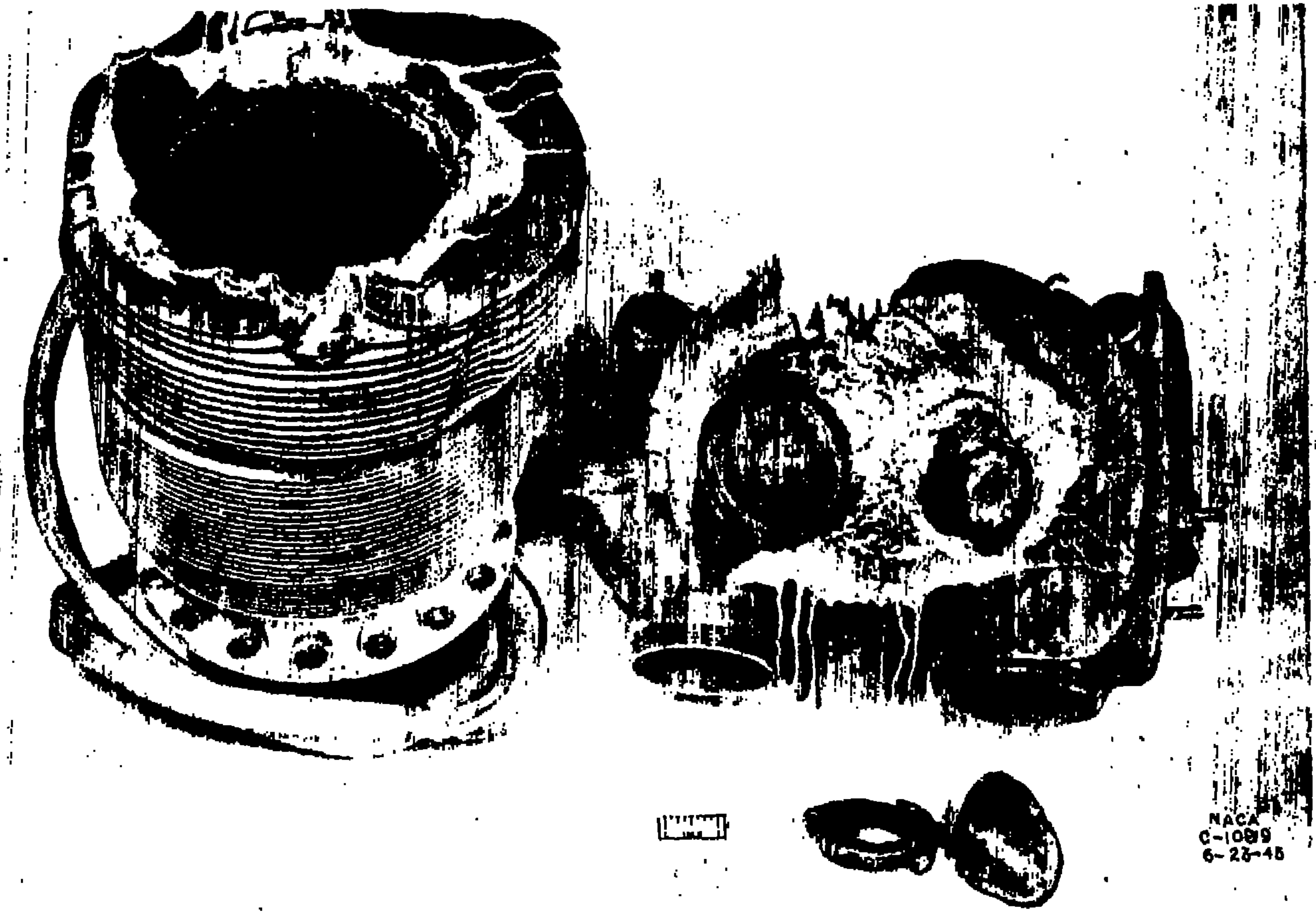

Figure 2. - Damaged cylinder resulting from exhaust-valve fracture. Rear-spark-plug-gasket temperature, 550° F; engine speed, 2600 rpm.

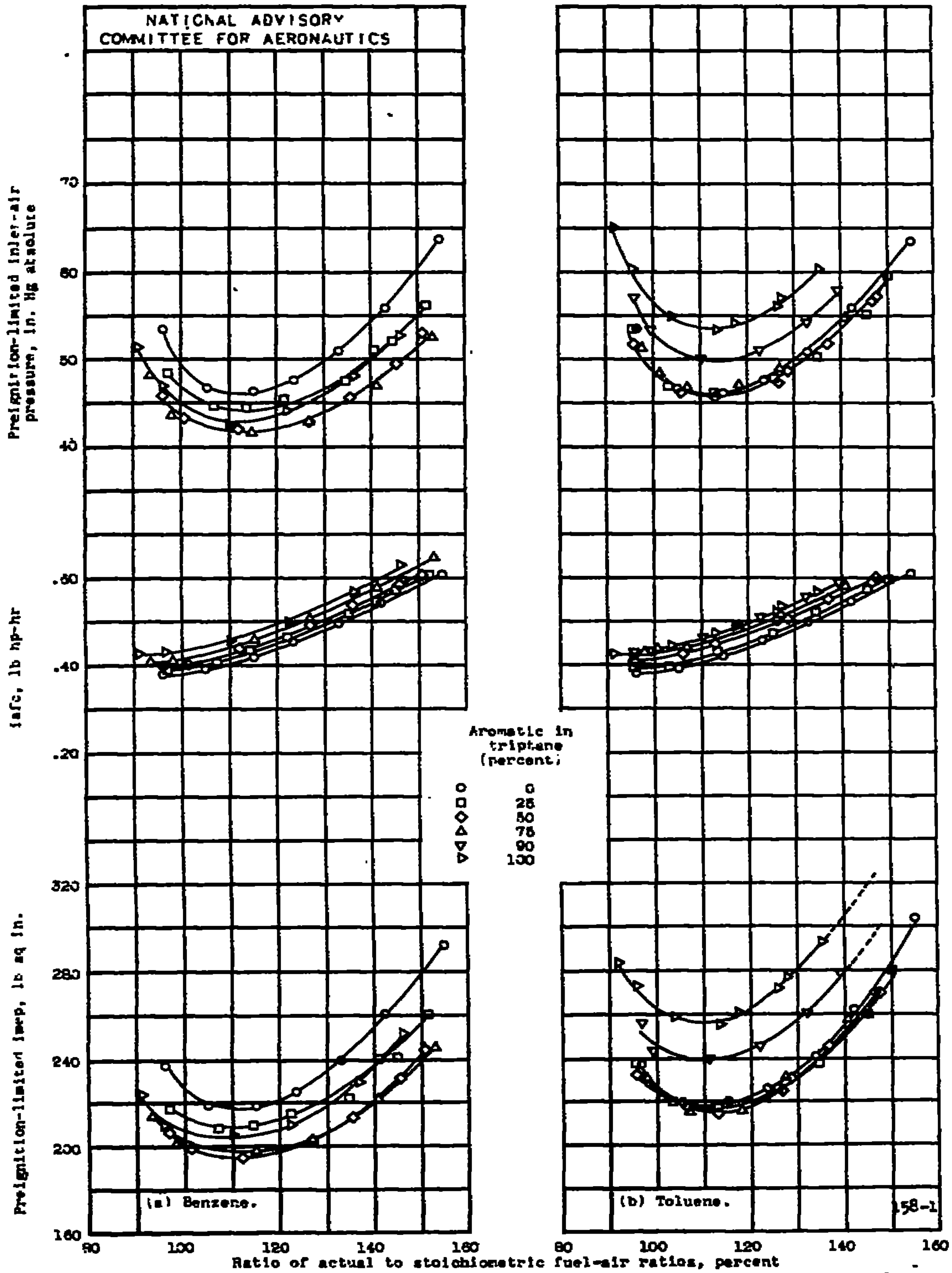

Figure 3. - Preignition-limited performance of blends of aromatics in triptane. All fuels contain 4.0 ml TEL per gallon. R-2800 cylinder; compression ratio, 6.75; spark advance, 20° B.T.C.; engine speed, 2600 rpm; inlet-air temperature, 260° F; rear-spark-plug-gasket temperature, 425° F.

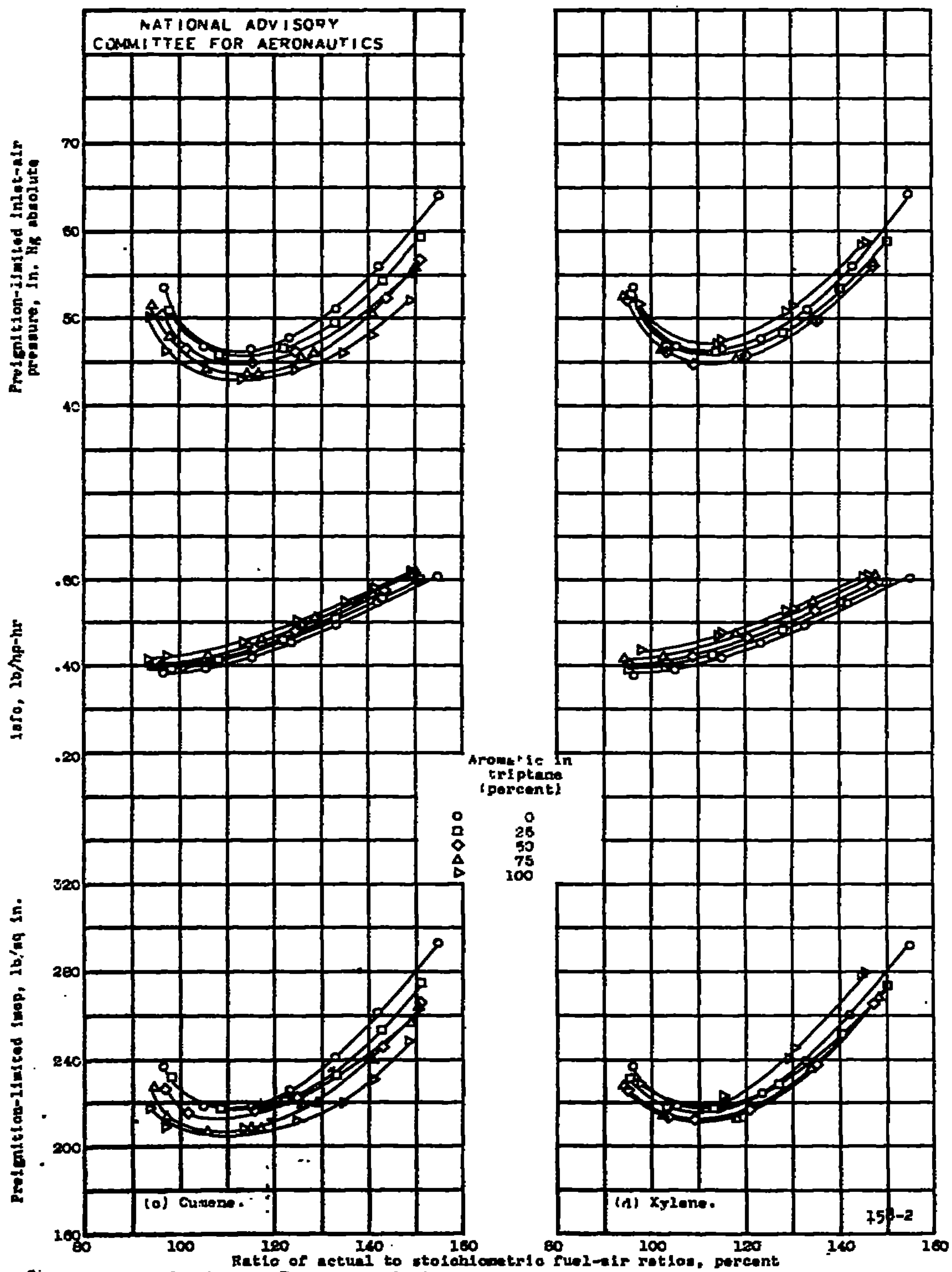

Figure 3. - Concluded. Preignition-limited performance of blends of aromatics in triptane. All fuels contain 4.0 ml TEL per gallon. R-2800 cylinder; compression ratio, 6.75; spark advance, 20° B.T.C.; engine speed, 2600 rpm; inlet-air temperature, 260° F; rear-spark-plug-gasket temperature, 425° F.

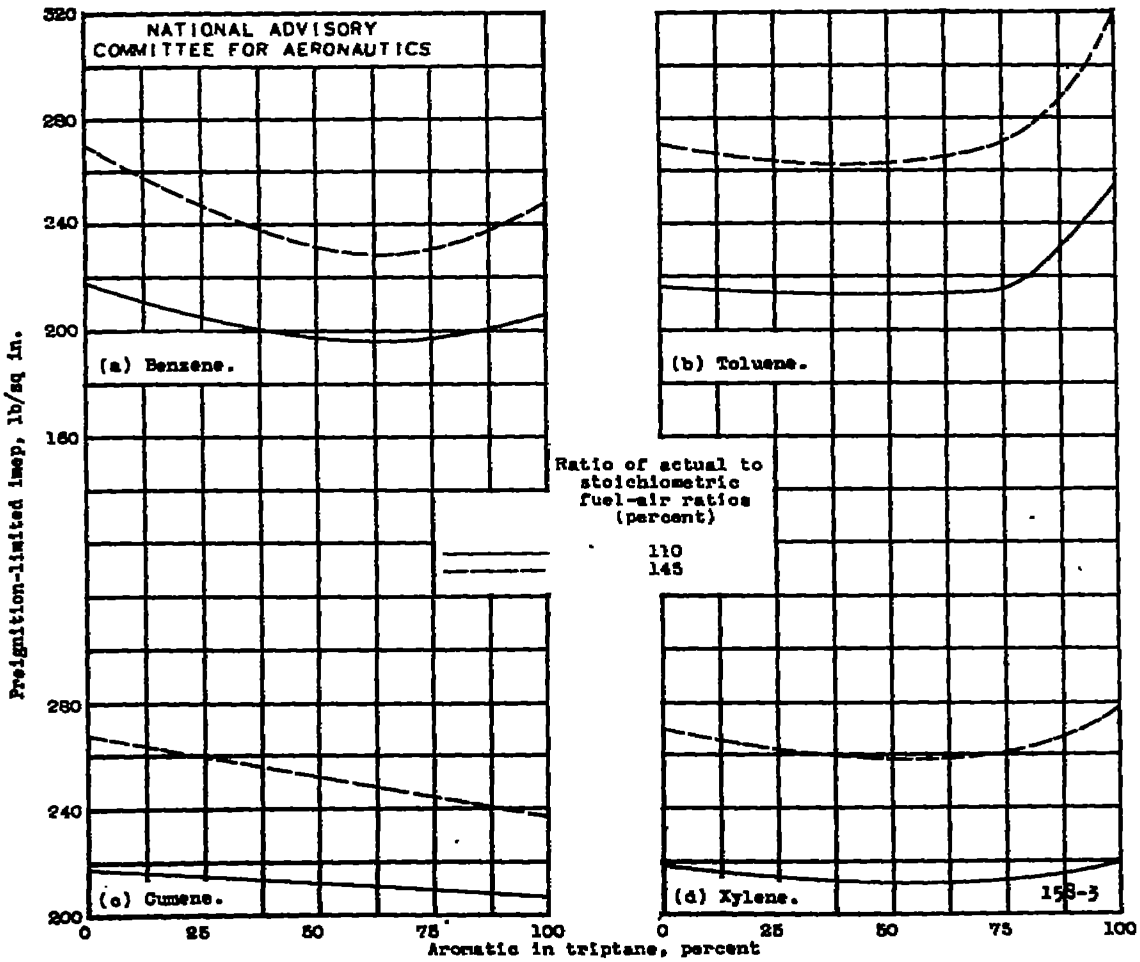

Figure 4. - Effect of aromatic content on preignition-limited indicated mean effective pressure at two mixture strengths. All fuels contain 4.0 ml TEL per gallon. R-2800 cylinder; compression ratio, 6.75; spark advance, 20° B.T.C.; engine speed, 2600 rpm; inlet-air temperature, 250° F; rear-spark-plug-gasket temperature, 425° F.

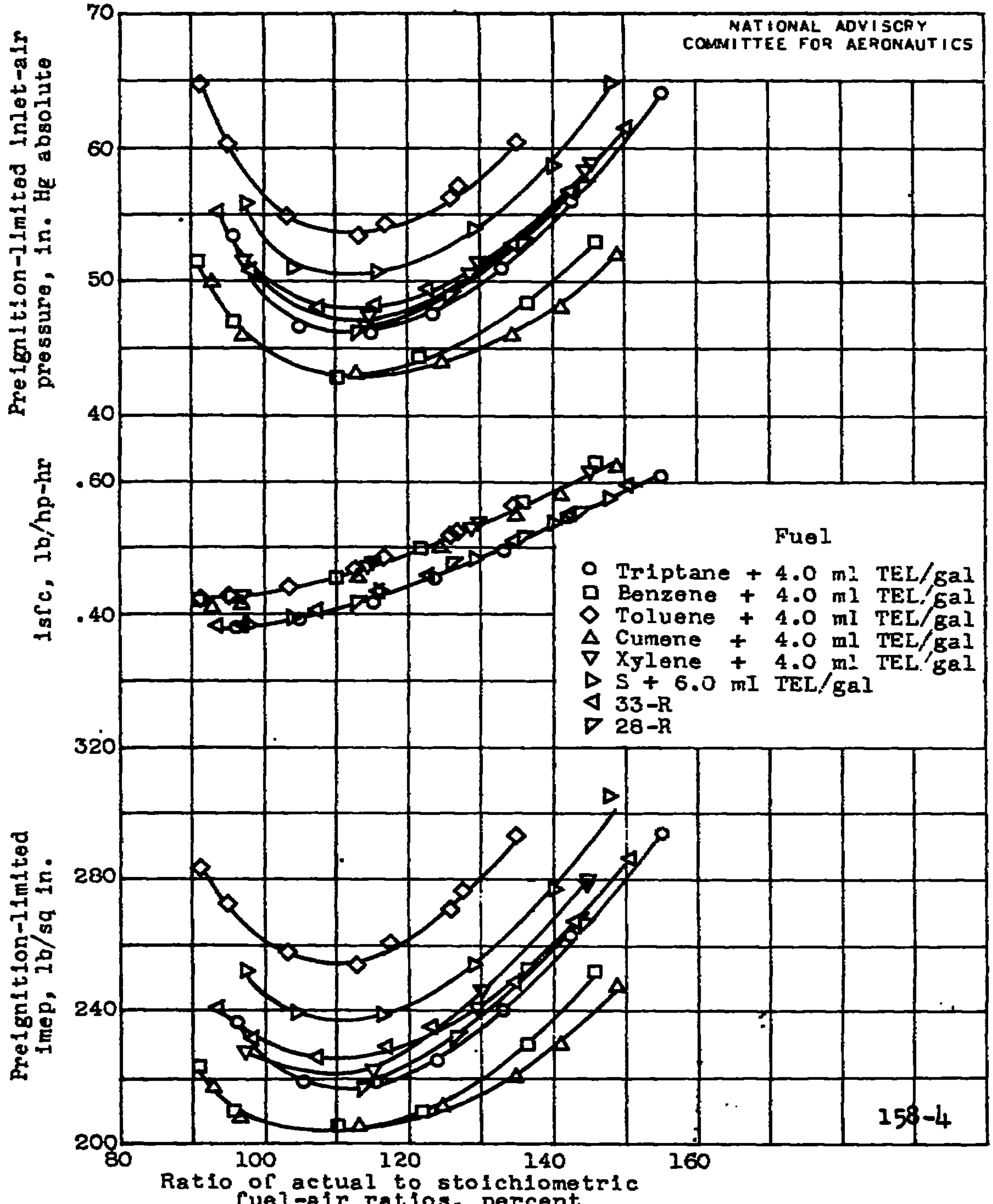

Figure 5. - Effect of fuel composition on preignition-limited performance. R-2800 cylinder; compression ratio, 6.75; spark advance, 20° B.T.C.; engine speed, 2600 rpm; inlet-air temperature, 260° F; rear-spark-plug-gasket temperature, 425° F.

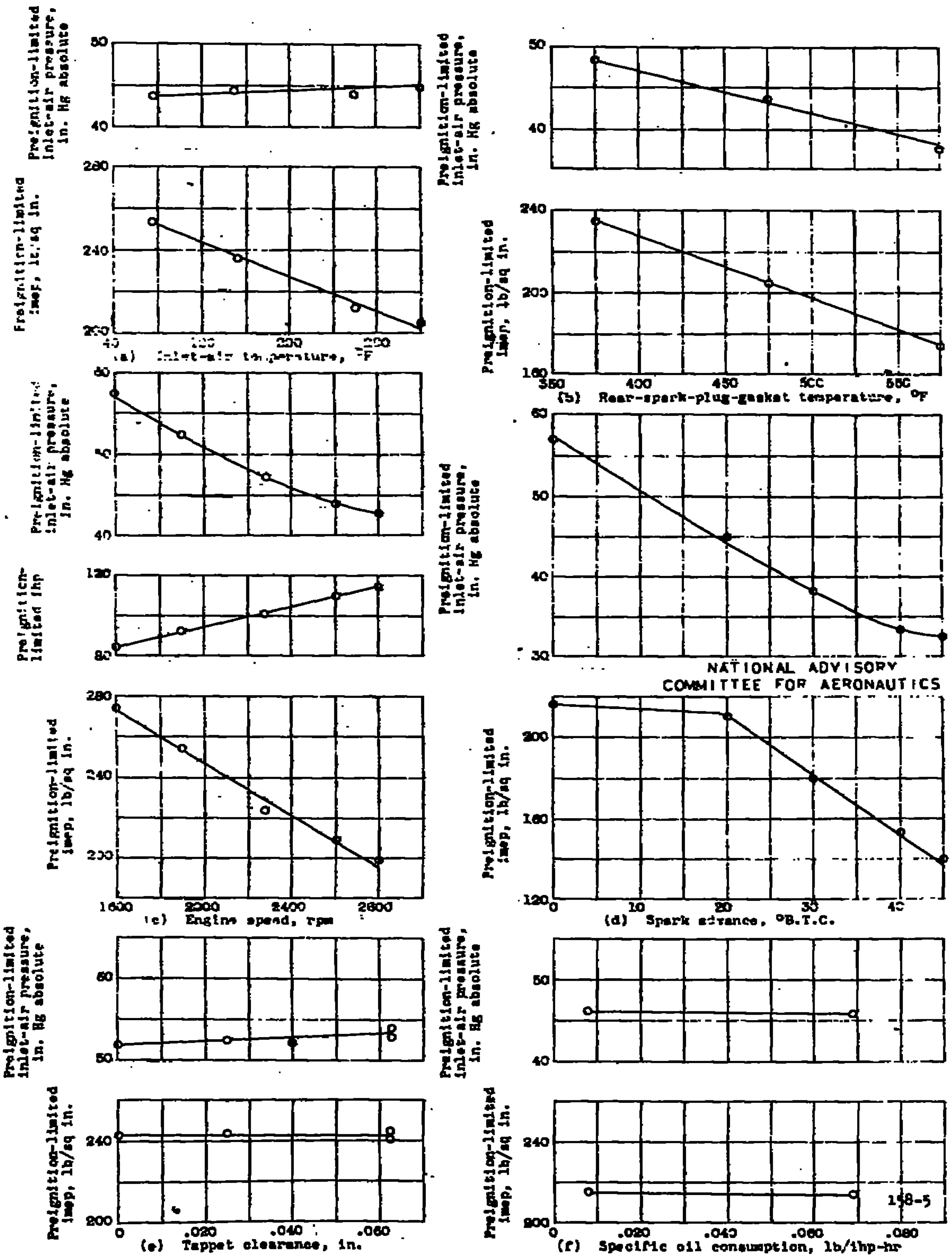

Figure 6. - Effect of six engine operating variables on preignition-limited performance. R-2800 cylinder; fuel-air ratio, 0.08; fuel, triptane + 4.0 ml TEL per gallon; compression ratio, 6.75.

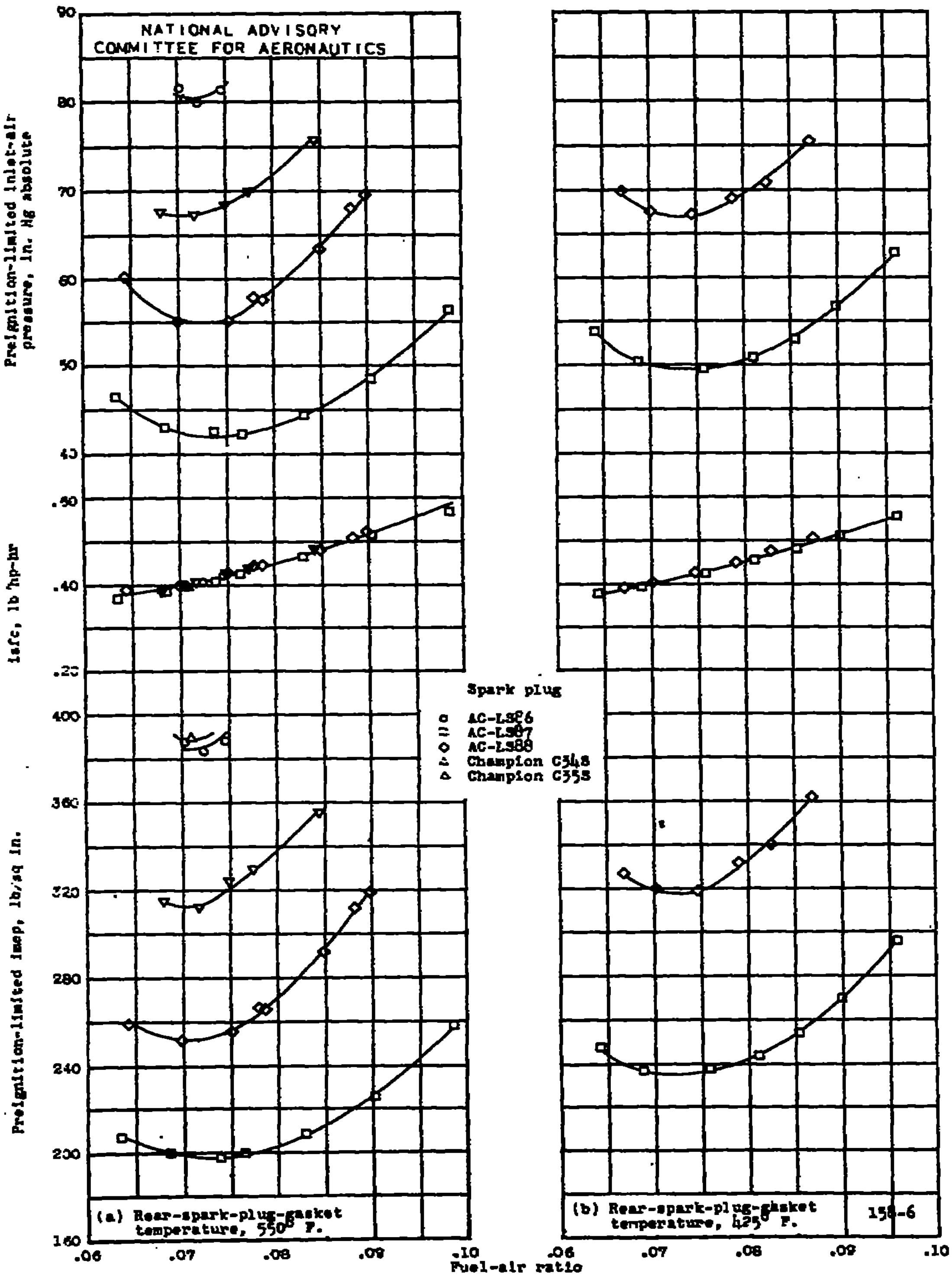

Figure 7. - Preignition-limited performance of R-2800 cylinder using five types of spark plug. Fuel, triptane + 4.0 ml TEL per gallon; compression ratio, 6.75; spark advance, 20° B.T.C.; engine speed, 2600 rpm; inlet-air temperature, 280° F.

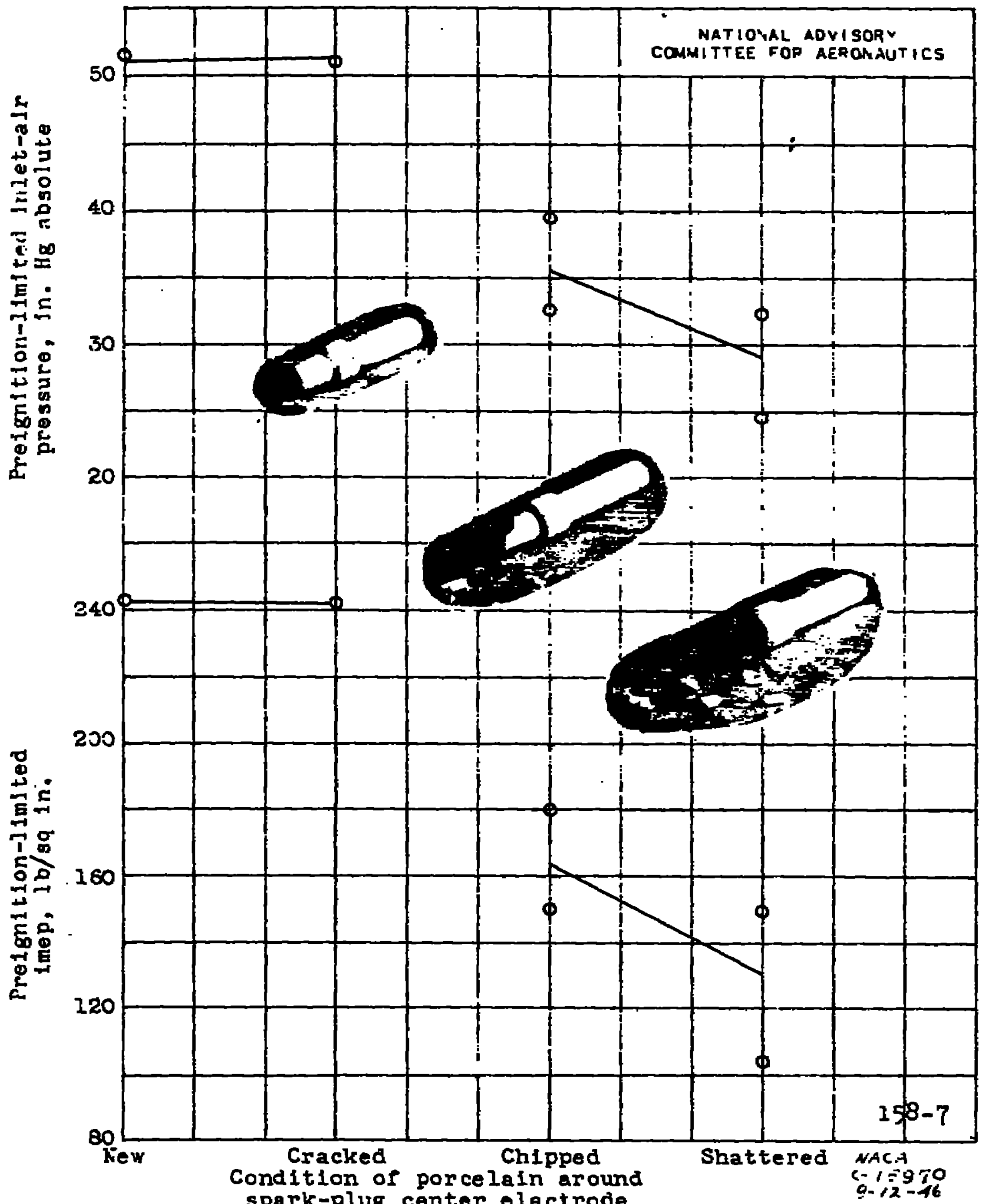

Figure 8. - Effect of condition of AC-LS87 spark plugs on preignition-limited performance. R-2800 cylinder; fuel, triptane + 4.0 ml TEL per gallon; fuel-air ratio, 0.08; compression ratio, 6.75; spark advance, 20° B.T.C.; engine speed, 2600 rpm; inlet-air temperature, 260° F; rear-spark-plug-gasket temperature, 425° F.

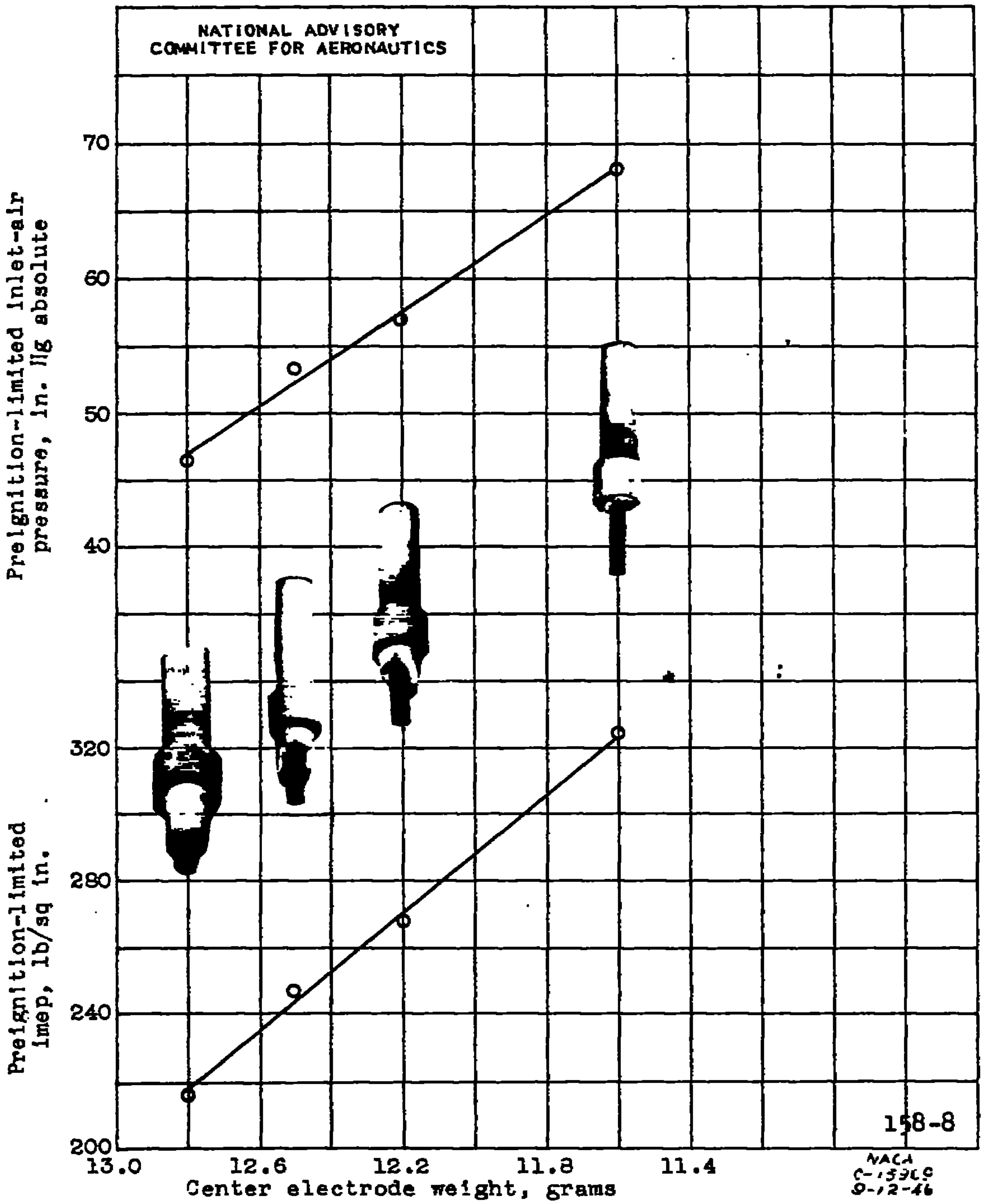

Figure 9. - Effect of porcelain removal from center electrode of AC-LS87 spark plug on preignition-limited performance. R-2800 cylinder; fuel, triptane + 4.0 ml TEL per gallon; fuel-air ratio, 0.08; compression ratio, 6.75; spark advance, 20° B.T.C.; engine speed, 2600 rpm; inlet-air temperature, 250° F; rear-spark-plug-gasket temperature, 425° F.

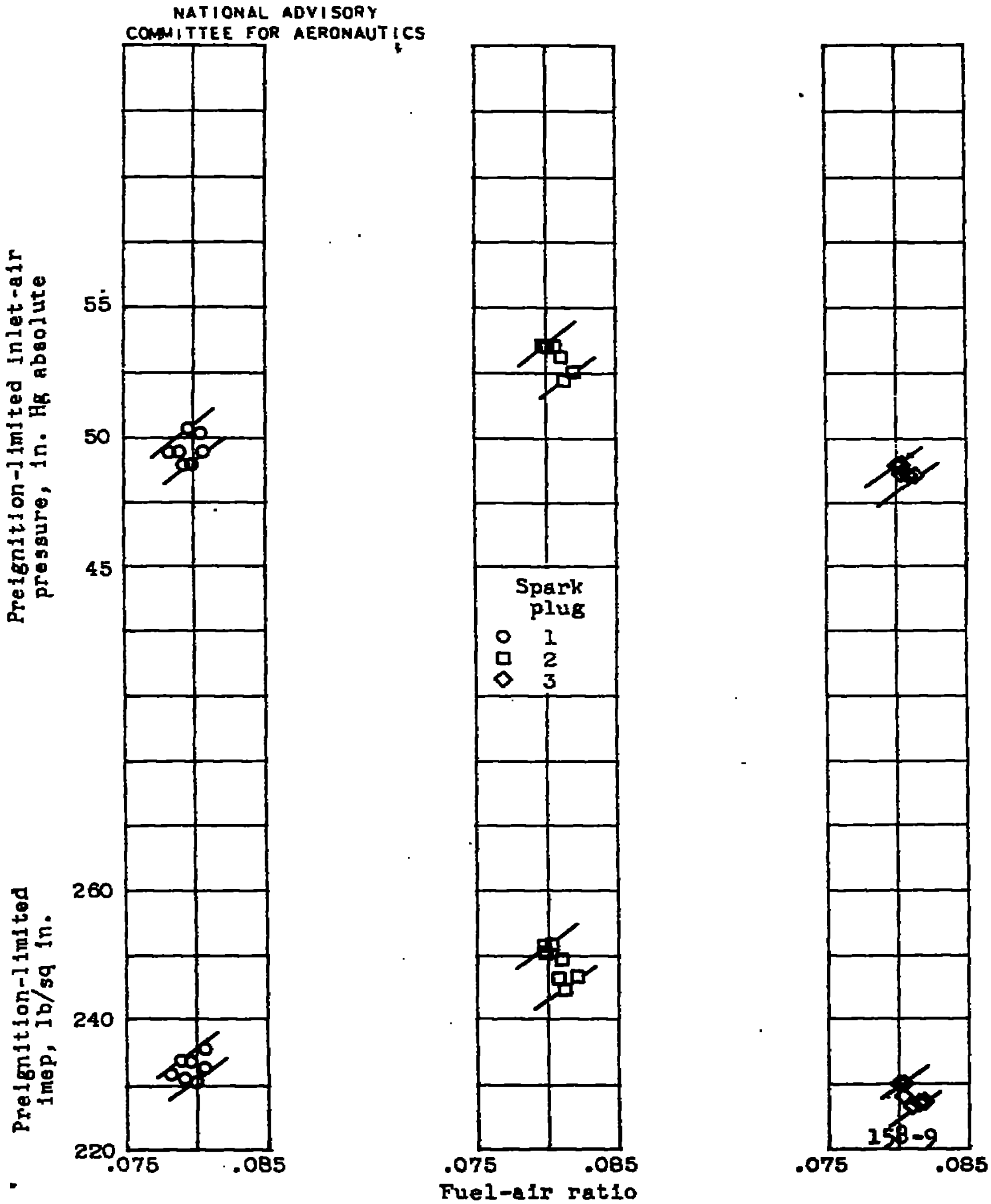

Figure 10. - Reproducibility of preignition limit with three AC-LS87 spark plugs. R-2800 cylinder; fuel, triptane + 4.0 ml TEL per gallon; compression ratio, 6.75; spark advance, 20° B.T.C.; engine speed, 2600 rpm; inlet-air temperature, 260° F; rear-spark-plug-gasket temperature, 425° F.

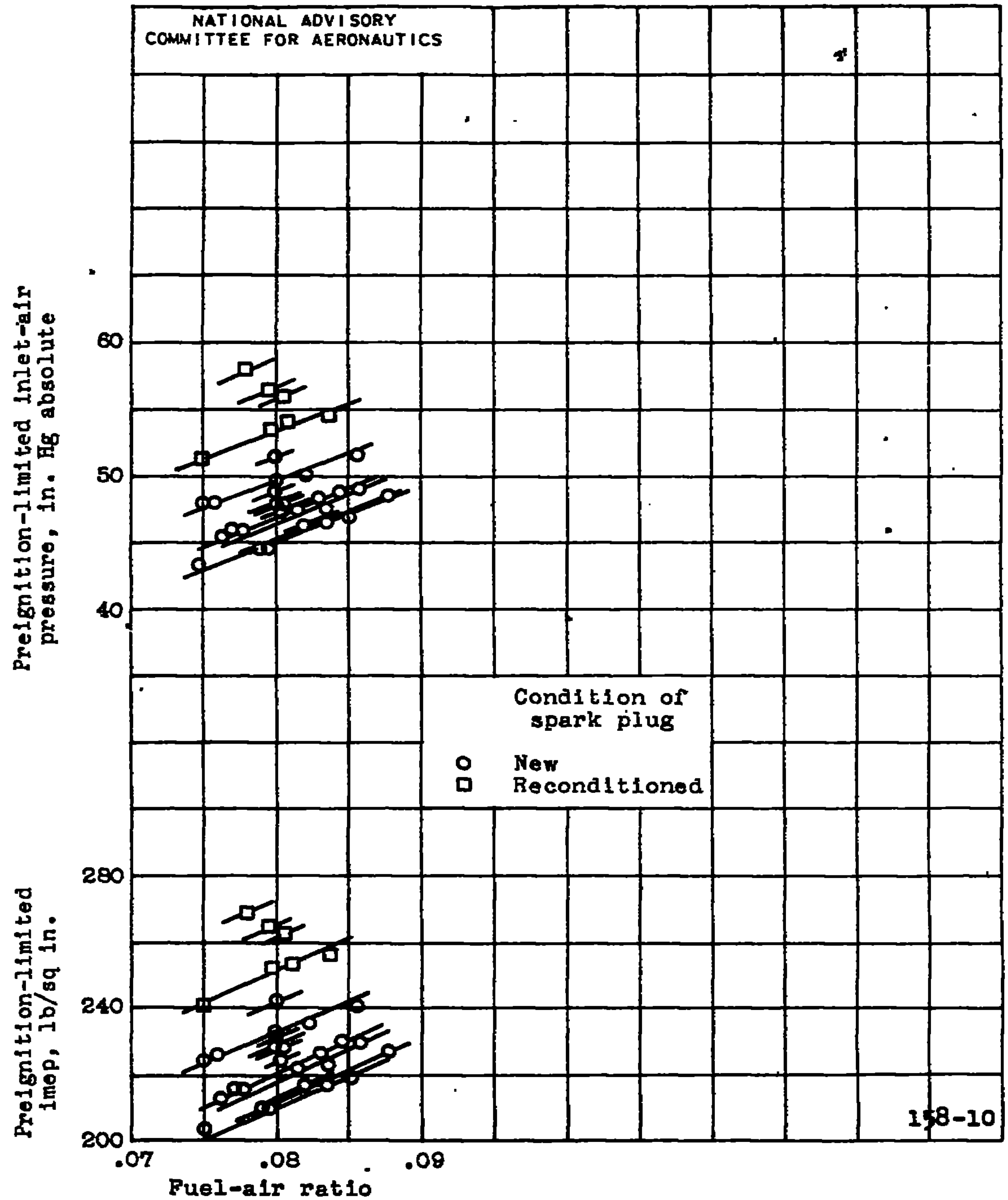

Figure 11. - Range of preignition limit of AC-LS87 spark plug. R-2800 cylinder; fuel, triptane + 4.0 ml TEL per gallon; compression ratio, 6.75; spark advance, 20° B.T.C.; engine speed, 2600 rpm; inlet-air temperature, 260° F; rear-spark-plug-gasket temperature, 425° F.

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Engine cylinder - Pratt & Whitney R-2800 [illegible]

[illegible] Champion [illegible]

Ignition - Pratt & Whitney R-2800-64

[illegible] - Firestone

[illegible]

[illegible] - Performance [illegible]

[illegible] - [illegible] 33-[illegible]

[illegible]

[illegible]

[illegible] - [illegible]

[illegible]

[illegible]

Spark plugs - AC-LS86
- AC-LS87