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EROSION OF SPARK-PLUG ELECTRODES

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MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

THE EFFECT OF HIGH-RESISTANCE IGNITION CABLE ON THE
EROSION OF SPARK-PLUG ELECTRODES

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SUMMARY

Engine tests were made using high-resistance ignition cable on an air-cooled five-cylinder radial auxiliary power plant operated at low mean effective pressure to determine the effects such cable would have on erosion of spark-plug electrodes. The brief tests showed that erosion was reduced about 70 percent when high-resistance ignition cable was used in place of standard cable on an engine equipped with nonresistor spark plugs and that the reduction was approximately the same when spark plugs with internal resistors were used with the standard cable. The combination of high-resistance cable and resistor spark plug resulted in the lowest rate of erosion, but the tests were too insensitive to make possible a quantitative evaluation of the combination.

INTRODUCTION

The use of high-resistance conductors in aircraft-engine ignition cable is one means of introducing resistance in series with the ignition spark. The use of lumped resistance at the spark plug reduces the rate of erosion of spark-plug electrodes (reference 1) and spark plugs incorporating small resistors for this purpose are now available. The use of distributed resistance in the cable conductor may be expected to have a similar effect on electrode erosion and, possibly, advantageous effects with respect to the reduction of radiation from the ignition system and the attenuation of voltage surges in the cable.

As part of an investigation of high-resistance cables requested by the Air Technical Service Command, Army Air Forces, engine tests

were made at the Cleveland laboratory of the NACA from March to May 1945 to determine what effect high-resistance cables would have on the erosion of spark-plug electrodes and are intended to show: (1) the decrease in erosion when high-resistance cable is used in place of standard cable on an engine with nonresistor spark plugs; and (2) a comparison of the erosion obtained with high-resistance cable to that obtained with a resistor spark plug. An attempt was made to evaluate the additional reduction in erosion obtained when high-resistance cable was used in place of standard cable on a resistor spark plug.

APPARATUS AND PROCEDURE

The effects on erosion of cable resistance and spark-plug resistance used either singly or in combination were investigated by means of 50-hour engine tests of each arrangement of resistance. Erosion rates were determined by feeler gages at 10-hour intervals during the tests and were compared with erosion rates for spark plugs operated with no series resistance. A 12-hour break-in run was made before each test to wear off any rough points on the electrodes.

The engine used for this series of tests was an auxiliary power plant, which is shown in figure 1. It is a 37-horsepower, air-cooled, five-cylinder radial engine operating a 30-volt, direct-current generator for supplying electrical power. The unit has the following specifications:

Displacement, cubic inches	75
Compression ratio	9:1
Normal operating speed, rpm	4000 \pm 100
Maximum continuous generator output, kilowatts	8
Ignition	Dual
Type of magnetos	Scintilla SF5RN12
Spark timing, deg B.T.C.	28

The energy output of the magnetos as shown by loading tests was as great as that of magnetos used on large aircraft engines.

The tests were run under the following conditions:

Speed, rpm	3400
Spark-plug (bottom row) gasket temperature, °F	300
Generator output, kilowatts	6.5

The fuel was AN-F-28, Amendment-2, containing 4.52 milliliters per gallon of tetraethyl lead. The spark plugs were C35S (nonresistor) and RC35S (resistor) with three of the four ground electrodes cut off to promote erosion at the remaining electrode. These spark plugs were used because it was desirable to obtain data on a type of spark plug that could be supplied both without and with an internal resistor. The resistance of a spark plug with an internal resistor was found to vary with temperature and is shown as a function of temperature in figure 2. The value is approximately 1000 ohms at room temperature. Brass spacers were used with the spark plugs because the engine was designed for short-reach spark plugs. In order to avoid excessive erosion by combustion-chamber gases, which might have masked electrical effects, the engine was operated at a power level that resulted in a moderate center-electrode temperature (800° - 900° F).

The ignition cables were either standard or high-resistance cables, depending on the test, and were shielded by metal braid. The high-resistance cable used in this investigation has a double spiral of fine resistance wire as the conductor. Constants for the two cables were as follows:

Cable	Length (ft)	Capacitance (μ mf)	Resistance (ohms)
Standard	7.5	190	Negligible
Resistance	5.5	190	925

As the capacitance was judged to be a large factor in erosion, the capacitances of the two cables were made the same. The standard cable was somewhat longer than the high-resistance cable because it had a lower capacitance per unit length.

Cables and spark plugs were installed in accordance with table I for the various test runs.

RESULTS AND DISCUSSION

The results of the three runs are shown in figure 3 in which the increase in electrode spacing is plotted as a function of length of run. Test 2(a) was made under the same conditions as test 1(a) and is not plotted. The points were determined from an average of the five spark plugs in the different cylinders. Occasionally, a spark plug would foul to the point where it would not fire because

of carbon deposits. In such cases, the assumption was made that the rate of erosion for the fouled spark plug would have been equal to the average rate for the other spark plugs during that 10-hour period if the fouled spark plug had continued to fire during the entire run. The fouled spark plug was cleaned at the end of the 10-hour period and the test continued. The two upper curves (standard cables and nonresistor spark plugs) show the greatest erosion and indicate that the erosion rates at the top and bottom rows were approximately equal; slightly more erosion occurred in the bottom-row spark plugs. The standard cable with the resistor spark plug and the high-resistance cable with the nonresistor spark plug both showed reduced, and approximately the same erosion. The high-resistance cable in combination with the resistor spark plug showed the smallest erosion although, as will be shown, the magnitude of the probable errors made the amount of reduction of erosion difficult to evaluate with precision.

At the conclusion of the tests the fouling was investigated. The spark plugs in the bottom row, which used high-resistance cable in tests 2 and 3, had shown a tendency to foul although the fouling occurred only occasionally and then in never more than one spark plug at any one time. For this reason various arrangements of cables and spark plugs were tried in the two rows. Tests showed that no fouling occurred with standard cables and nonresistor spark plugs but that the introduction of series resistance, either by means of resistor spark plugs, high-resistance cables, or both, resulted in occasional fouling in the bottom row. Because the occurrence of fouling is an erratic phenomenon, the results of these brief tests can be taken merely as an indication that the effects of series resistance on spark-plug fouling may require investigation.

Inasmuch as the resistance of a resistor spark plug changes with temperature an attempt was made to determine the approximate resistance of the resistor spark plug during the engine tests. At a temperature of 300° F, such as was estimated for the operating temperature of the resistor, the resistance would be about 700 ohms. (See fig. 2.) This value is somewhat lower than the 925-ohm value of the high-resistance cables. The tests reported in reference 1 indicate, however, that erosion is not extremely sensitive to the magnitude of the resistance in the neighborhood of 1000 ohms.

Table I shows the results of computations made to determine the amount of reduction in erosion of the various tests. The mean erosion rate was determined by applying the method of least squares on the assumption that the mean rate was constant throughout each test. By the use of the values obtained, the ratio of the erosion

with resistance to the erosion without resistance was determined and results of the same row were compared. In the determination of the probable errors, an observation error of 0.5 mil was assumed. This value is consistent with the observed scatter of the measurements. Table I shows that either the high-resistance cable or the resistor spark plugs reduced erosion by approximately 70 percent. The magnitudes of the probable errors are such that little significance can be attached to the considerably larger reduction in erosion indicated by test 3(b) when the resistance cable and resistor spark plugs were used in combination.

In the interpretation of the results of the erosion tests, account must be taken of the fact that the standard and resistance cables were compared on the basis of equal capacitances and not on the basis of equal lengths. Thus, the results do not apply to the practical case of substitution of high-resistance cable for standard cable in an ignition harness but rather to the idealized case of replacement of the standard cable by a theoretical resistance cable having a capacitance per unit length equal to that of the standard cable.

SUMMARY OF RESULTS

Spark-plug-electrode erosion tests were made at low mean effective pressure on an air-cooled, five-cylinder radial auxiliary power plant to compare the reduction in erosion resulting from the use of high-resistance ignition cable with that resulting from the use of resistor spark plugs and standard ignition cable. The results of the comparisons, which were made on the basis of equal cable capacitances rather than equal cable lengths, were as follows:

1. The high-resistance cables reduced erosion 70 percent when used in place of standard cables on nonresistor spark plugs.
2. Resistor spark plugs reduced erosion to approximately the same amount as did the high-resistance cables.
3. The combination of high-resistance cables and resistor spark plugs resulted in the lowest rate of erosion, but the tests were too insensitive to make possible a quantitative evaluation of the combination.

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REFERENCE

1. Bairsto, G. E.: Some Factors Controlling the Development of Electrical Ignition of Aero Engines. R.A.S. Jour., vol. XLIV, no. 350, Feb. 1940, pp. 119-175.

TABLE I - TABULATION OF SPARK-PLUG-ELECTRODE EROSION TESTS

Test	Row	Type of cable	Type of spark plug	Mean erosion rate (mils/hr)	Erosion with resistance		Probable error
					Erosion without resistance		
1(a)	Top	Standard	Nonresistor	0.161			
1(b)	Bottom	---do---	---do---	.171			
2(a)	Top	---do---	---do---	.158			
2(b)	Bottom	Resistance	---do---	.051	2(b)/1(b) = 0.30		±0.04
3(a)	Top	Standard	Resistor	.045	3(a)/1(a) = .28		±.04
3(b)	Bottom	Resistance	---do---	.030	3(b)/1(b) = .18		±.03

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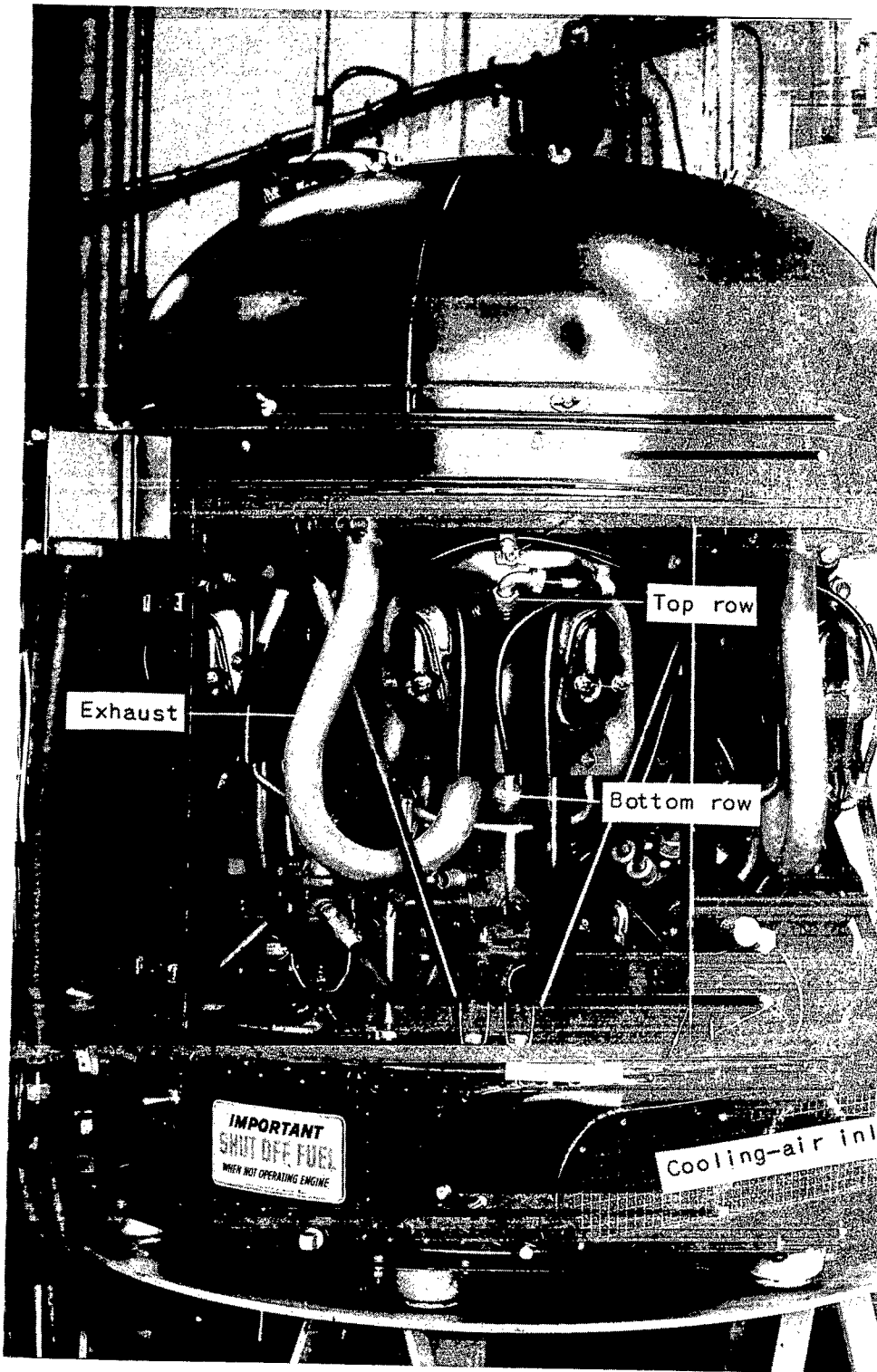


Figure 1. - Air-cooled, five-cylinder radial auxiliary power unshielded ignition cables.

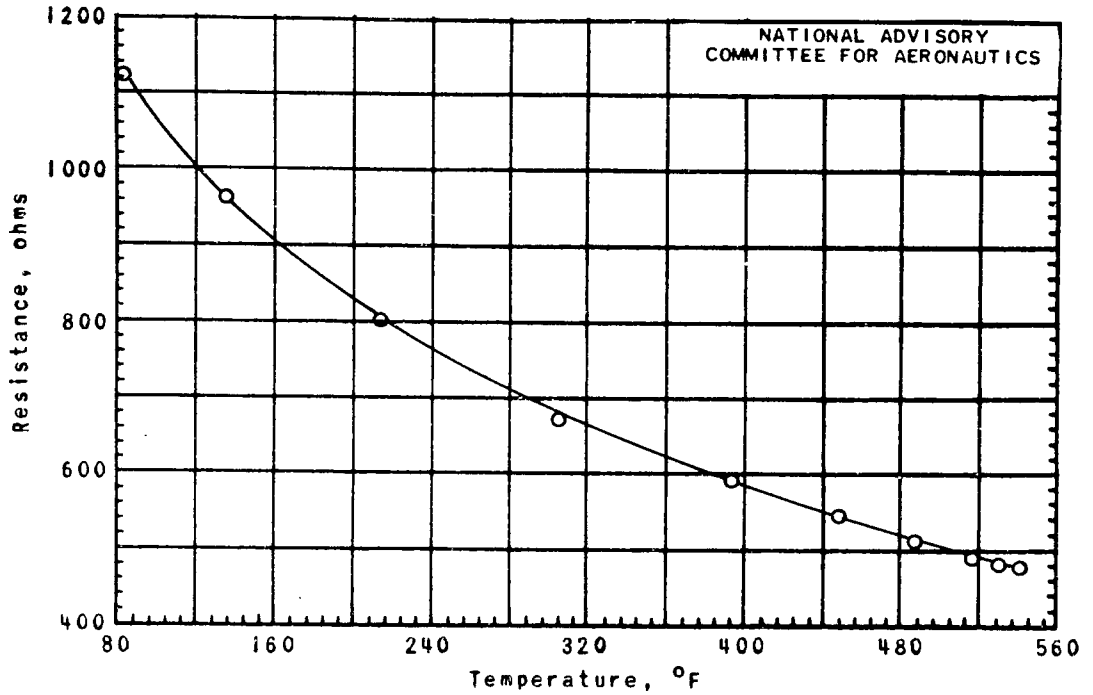


Figure 2. - Effect of temperature on resistance of resistor in resistor spark plug. Spark plug heated in oven; resistance measurements made with Wheatstone bridge.

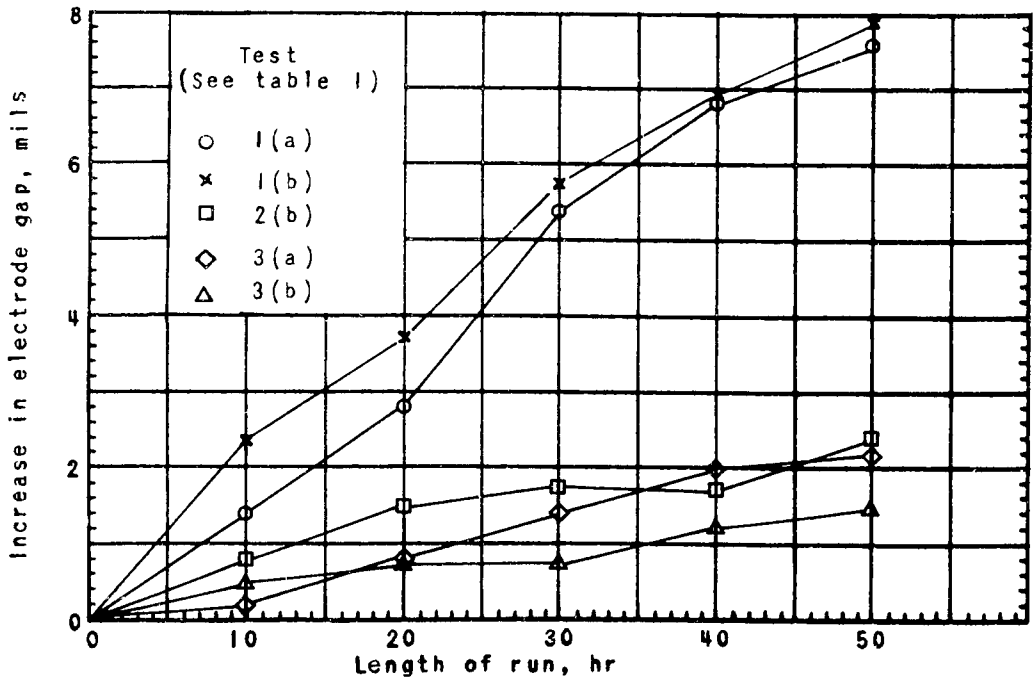


Figure 3. - Increase in electrode gap with time for various combinations of cables and spark plugs. Air-cooled, five-cylinder radial auxiliary power plant; engine speed, 3400 rpm; generator power output, 6.5 kilowatts; fuel, AN-F-28, Amendment -2, with 4.52 milliliters tetraethyl lead per gallon; three ground electrodes removed from spark plugs; capacitance of ignition cables, 190 $\mu\mu\text{f}$; resistance of high resistance cables, 925 ohms.

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