RB No. E5A31

E-70

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

February 1945 as
Restricted Bulletin E5A31

A PREIGNITION INDICATOR FOR AIRCRAFT ENGINES

By Thomas Dallas, Gene Hoss
and Myron L. Harries

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESTRICTED BULLETIN

A PREIGNITION INDICATOR FOR AIRCRAFT ENGINES

By Thomas Dallas, Gene Hoss
and Myron L. Harries

SUMMARY

An electrical-relay circuit that uses cylinder thermocouples as the primary element for indicating preignition or misfiring in an aircraft engine is described. In its present form the indicator was used on a 12-cylinder liquid-cooled engine mounted on a dynamometer stand, but the circuit principle is equally applicable to any engine.

On the test engine the indicator gave warning, by means of a system of panel lights, when any cylinder varied more than 34° F on either side of its normal operating temperature. It also indicated which cylinder was malfunctioning and whether the cylinder was too hot or too cold.

INTRODUCTION

In the course of tests conducted at the NACA Cleveland laboratory for the determination of the knock-limited power of aircraft engines at high outputs, it was necessary to insure against engine failures resulting from preignition. Engine failure from preignition is particularly insidious because it can occur in a few seconds with little or no warning. For this reason, the primary requisites of a successful preignition indicator are a short response time and the ability to give a positive indication of preignition. The ultimate aim is an instrument for experimental flight tests that is light, rugged, and reliable.

Pressure-actuated knock-detection equipment has been used by the United Air Lines and Standard Oil Company of California to indicate the existence of preignition, but the installation of knock pickups requires considerable engine modification and with liquid-cooled engines this modification is generally impracticable.

A preignition indicator that uses thermocouples for the primary element was tested on a single-cylinder Allison engine and a 12-cylinder V-1710 Allison engine mounted on a dynamometer stand. This indicator, which prevented damage to the 12-cylinder engine by consistently giving reliable warning of preignition, is described in this report.

OPERATING PRINCIPLE

That preignition leads to a general rise in cylinder temperature is well known. For good sensitivity, therefore, a control point for thermocouple installation should be chosen that responds rapidly to this temperature rise. Because of cylinder shape some locations are inaccessible; a control point was selected, however, between the two exhaust-valve seats of the single-cylinder test engine and a thermocouple was installed to check its temperature response. (See fig. 1.)

In these tests, preignition was induced by a hot spark plug. A reliable indication of the start of preignition was obtained with a piezoelectric pressure pickup and an oscilloscope by observing the horizontal shift in the pressure trace. In order to check the response, preignition was induced at a variety of engine conditions: the fuel-air ratio was varied from 0.065 to 0.109, the brake mean effective pressure was varied from 123 to 311 pounds per square inch, and the engine speed was varied from 1600 to 3000 rpm. Under every type of condition, the cylinder-head temperature began to rise with the onset of preignition.

Methods of Indicating Preignition

In the utilization of the temperature rise for indicating preignition, an instrument can operate either on the rate of temperature rise or on the total increase in temperature above the normal temperature for the given engine conditions. The utilization of the rate of temperature rise would require vacuum tubes and, even if the simplest vacuum-tube circuit were used to protect a given cylinder, a circuit with the required rectifier power supplies to accommodate each cylinder of a multicylinder engine would result in a complicated, heavy instrument. The use of the rate of temperature rise was therefore abandoned in favor of a sensitive moving-coil circuit that can operate on the total temperature increase.

The use of the total increase in temperature as an indication of preignition was first checked on the 12-cylinder test engine with an indicator employing light-beam galvanometers. The voltage for each galvanometer came from the differentially connected thermocouples of a pair of cylinders; thus, 6 galvanometers protected 12 cylinders. The system functioned satisfactorily but the chief disadvantage was that, when the first cylinder of a pair was colder than normal because of misfiring, it nevertheless gave the identical indication that the second cylinder of the pair gave if the second cylinder was hotter than normal. Also, in this circuit, indication was not automatic and an observer was required to keep constant watch during tests. Negligence on the part of the observer for only a few seconds could be sufficient to allow engine failure.

Theory of Operation of Sensitive Moving-Coil Circuit

In the indicator that was developed to provide a more nearly automatic system, three cylinders function as a unit. If the temperature of one of the three cylinders is appreciably lower or higher than the other two, the indicator will give a warning. The circuit utilizes the Sensitrol relay manufactured by the Weston Electrical Instrument Corporation. This relay is essentially a combination millivoltmeter and relay and, as shown by the simplified circuit diagram of figure 2, the deflecting-coil voltage of each Sensitrol relay is obtained from two differentially connected thermocouples.

With the relays connected as shown in figure 2, if one cylinder is hotter than the other two in a group, the pointers of two relays will deflect toward each other; similarly, if one cylinder is colder than the other two, the pointers of two relays will deflect away from each other. Furthermore, the combination of deflections caused by a given hot or cold cylinder is unique.

As an example, assume cylinder 3 preignites and is therefore hotter than cylinders 1 and 2. (See fig. 2.) Current will flow from cylinder 3 to cylinder 2, through the deflecting coil of relay B, and back to cylinder 3. Another current will flow from cylinder 3 to cylinder 1, through the coil of relay C, and back to cylinder 3. The pointer will deflect away from the terminal through which the current enters the relay by choosing the correct relative directions of deflecting-coil winding and permanent magnet field of the Sensitrol relay. If this assumption is made, the pointers of relays B and C will deflect toward each other and contacts 1 and 4 on relay B and 1 and 5 on relay C will be connected. This connection is unique; no other hot or cold cylinder will set up this combination. It is therefore possible to connect warning circuits that will indicate any hot or cold cylinder.

It should be pointed out, however, that a false warning will be given if two of the three cylinders in any set should simultaneously preignite. For instance, if cylinders 1 and 2 preignite, the indicator will show misfiring in cylinder 3. The possibility of the occurrence of this condition is considered to be remote. A condition more likely to occur is simultaneous misfiring in two cylinders; the indicator will then erroneously indicate preignition in the third cylinder.

By the method of connection shown in figure 2, two limits are set on cylinder operation with a single relay for each cylinder. Because two or more relays are required with more conventional methods, the panel is greatly simplified and materially reduced in weight by this method of connection.

DESCRIPTION OF PREIGNITION INDICATOR

Description of Relay

Because it is possible to obtain Sensitrol relays with various modifications, the description that follows will necessarily be limited to the relays used in the indicator. The relay construction is such that the indicating pointer closes an electrical contact at either an increasing or a decreasing value of input voltage. Positive connection is provided and chattering between contacts is eliminated in the Sensitrol relay by two small permanent magnets that serve as the fixed contacts and a small iron rider on the pointer that serves as the moving contact. The Sensitrol is a locking-type relay and a solenoid reset mechanism is provided for disengaging the pointer from the fixed magnetic contact. When sufficient input voltage has been applied, the deflection of the pointer places the iron rider within control of the magnetic field of the fixed contact, which attracts the pointer through the rest of the distance and accomplishes contact.

Indicator Circuit

The actual circuit used in the indicator complete with warning circuits is shown in figure 3 for a set of three Sensitrol relays. This circuit will accommodate any engine having an integral multiple of three cylinders; four such circuits were used on the 12-cylinder test engine. When cylinder 3 is preigniting under the conditions of the example previously described, the 95-volt power supply will energize the relay 3H through the Sensitrols B and C and a warning light, controlled by relay 3H, will indicate that cylinder 3 is hot. Figure 4 is a photograph of the panel used with the 12-cylinder test engine installation and shows the warning lights and the Sensitrol relay dials.

The warning lights were operated through intermediate relays because the Sensitrol relay contacts are limited to 5 watts at 110 volts. (See fig. 3.) Each intermediate relay is a double-pole midget relay, which has a rating of 30 milliamperes at 115 volts a-c. but which will operate reliably at 80 volts. Only one pole is required for the light-warning circuit; the other pole may be used to operate a buzzer or some other supplementary warning device.

The three-phase power supply for the warning circuit was obtained from a 110-volt single-phase source. (See figs. 5 and 6.) The primary of an isolation transformer of 1:1 ratio was connected to the 110-volt source. The two identical 110-volt secondaries formed a three-phase open-delta system when connected to suitable values of resistance, inductance, and capacitance. Space was saved by using the primary of the warning-light transformer for the inductance L. The correct inductance was obtained by restacking the transformer core and leaving a small air gap.

Calibration

A bench test was made in which an actual engine indicator was simulated by connecting aluminum-constantan thermocouples to the Sensitrol relays as shown in figure 2 in order to determine the temperature differential required to operate the Sensitrols. Aluminum wire rather than aluminum alloy was used because no material having the composition of the test cylinder head was available. Another purpose of this test was to demonstrate that the temperature differentials required to operate the Sensitrol relays are substantially unaffected by the brass wire because, in the engine installation described later in the report, brass wire is essentially in parallel with the aluminum-alloy legs of the thermocouples. The test results shown in table 1 were obtained by differentially heating three aluminum-constantan couples whose junctions were joined with brass wire in one instance but not in the other; the results prove that the Sensitrols are unaffected by the brass wire.

TABLE 1. - TEMPERATURE DIFFERENCE REQUIRED TO OPERATE SENSITROLS

Cylinder	Thermocouples without brass wire		Thermocouples with brass wire	
	Hot (°F)	Cold (°F)	Hot (°F)	Cold (°F)
1	27.0	32.5	25.0	31.5
2	32.5	27.0	30.5	27.0
3	29.0	28.0	30.5	29.0

The indicator was partly recalibrated after it was installed on the 12-cylinder test engine by injecting water into individual cylinders. The drop in temperature required to operate the indicator ranged from 23° F to 34° F and closely checked the values of table 1. The temperature drop required for a hot-cylinder condition (simulated by the simultaneous injection of water to the other two cylinders of a set) checked within 2° F the values previously found for the same cylinder.

Although it requires approximately 4 seconds for the Sensitrol relays to make contact after application of 150 percent of full-scale voltage, the speed of response is adequate. Unpublished data from the single-cylinder engine used in the preliminary tests show that the rise in cylinder-head temperature ranged from 3.5° F to 23.2° F per second. If the temperature response was at the lowest rate of 3.5° F per second, it would require approximately 10 seconds to reach the tripping temperature of the Sensitrol relay. The lower rates of temperature rise are, however, at the less severe engine conditions (low engine speed or low bmep). In one test on the single-cylinder engine, preignition was allowed to continue for 11.1 seconds, during which the temperature rose 52° F, at fairly severe engine conditions (engine speed, 2600 rpm; bmep, 308 lb/sq in.); no engine damage occurred.

Thermocouple Installation

In a current test installation on the 12-cylinder engine, iron-constantan thermocouples located as shown in figure 1 are used in conjunction with a potentiometer to measure cylinder-head temperatures. The 12 constantan wires of this system are used for the preignition indicator to form a thermocouple system of constantan-alluminum-alloy couples having the aluminum-alloy sides common. (See fig. 2.) The potentiometer-thermocouple system has a junction box near the engine and copper wires instead of constantan wires are connected from this box to the preignition indicator in order to reduce the resistance of the indicator-thermocouple circuits. The thermal voltages are not altered by this arrangement. For the voltage at the Sensitrol relays to be approximately equal to the generated thermocouple voltages, the resistance of the external thermocouple circuit should be below 2.5 ohms, or about 5 percent of the 50-ohm resistance of the Sensitrol deflecting coil.

Thermocouple installations must be carefully made because an improper or careless installation can cause much trouble in the indicator operation. The potentiometer circuits are undisturbed because the iron-constantan wires are firmly welded together. Peening the iron-constantan thermocouples directly into holes in the cylinder head was unsatisfactory for the indicator because vibration often caused high-resistance or open connections between the aluminum-alloy head and the embedded thermocouple at these points. These high-resistance or open connections often caused false indications of preignition to appear on the warning system using the light-beam galvanometers; however, this trouble was eliminated by silver-soldering the iron and constantan wires to small brass plugs, which were then peened into holes in the cylinder heads. Satisfactory operation was also obtained by another installation in which the plugs were interconnected with ordinary brass safety wire to further insure a complete thermocouple circuit. Although brass and aluminum have approximately equal thermoelectric powers, inasmuch as the cylinder head is made of aluminum alloy, it may be necessary in some installations to select a brass wire of suitable composition.

Because the normal operating temperatures of all cylinders are not exactly the same in the 12-cylinder test engine, it was necessary to reset the zero adjustment of each Sensitrol relay after the engine was running normally. In extreme cases of varying cylinder temperatures, it may be necessary to group selectively the thermocouples to interconnect cylinders having similar operating temperatures. The possibility of high electrical-resistance connections and spurious thermoelectric voltages makes it inadvisable, however, to interconnect thermocouples from both blocks of a V-type liquid-cooled engine and such a connection should be avoided if possible.

The indicator was extremely useful in locating misfiring spark plugs, particularly when the 12-cylinder engine was operating with a closed exhaust system. When either side of the dual ignition was switched off during a magneto check, a cylinder containing a misfiring plug was indicated as being cold.

Although the indicator was tested on only a liquid-cooled engine, it can be used on an air-cooled engine if a sufficiently responsive thermocouple installation can be made. It is believed that a thermocouple which indicates the temperature near the exhaust-valve seat would qualify.

For installation of the indicator on a 14-cylinder engine, the requisite integral multiple of three cylinders for installation of the indicator could be simulated by installing two thermocouples on one of the cylinders.

SUMMARY OF RESULTS

In each instance during a series of preignition tests on the 12-cylinder test engine, the indicator designated the preigniting cylinder reliably and quickly. In many of the runs, after the preigniting cylinder had been designated by the indicator, the indication was checked by noting the rapid rise of the cylinder-head temperature with a self-balancing potentiometer.

Because the 12-cylinder engine did not have a constant-speed control, preignition was detected by a drop in engine speed. Care is necessary, however, to distinguish a normal drop in speed, occurring from a change in engine conditions, from the drop in speed caused by preignition.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

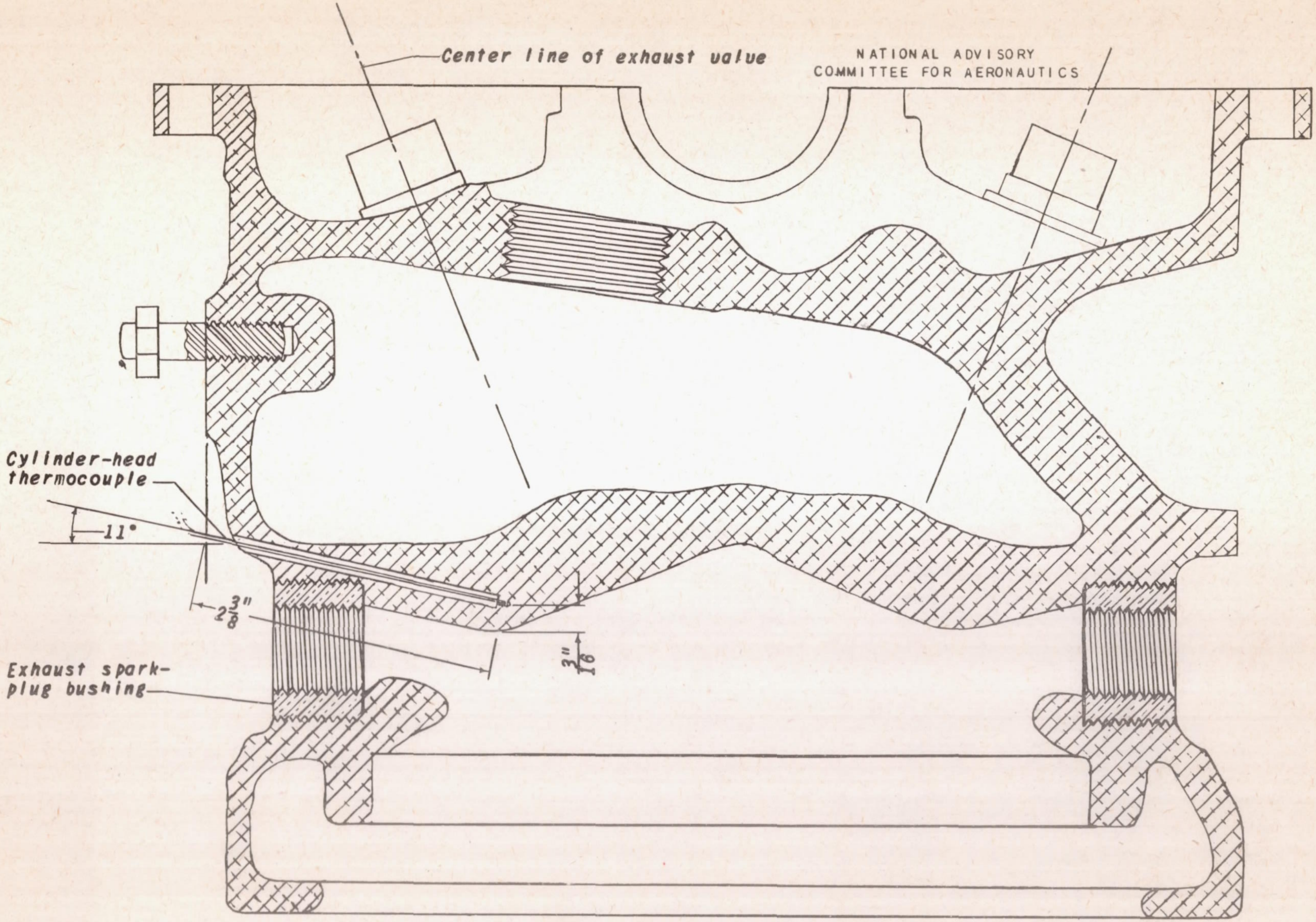


Figure 1. - Section through the cylinder head showing location of the thermocouple.

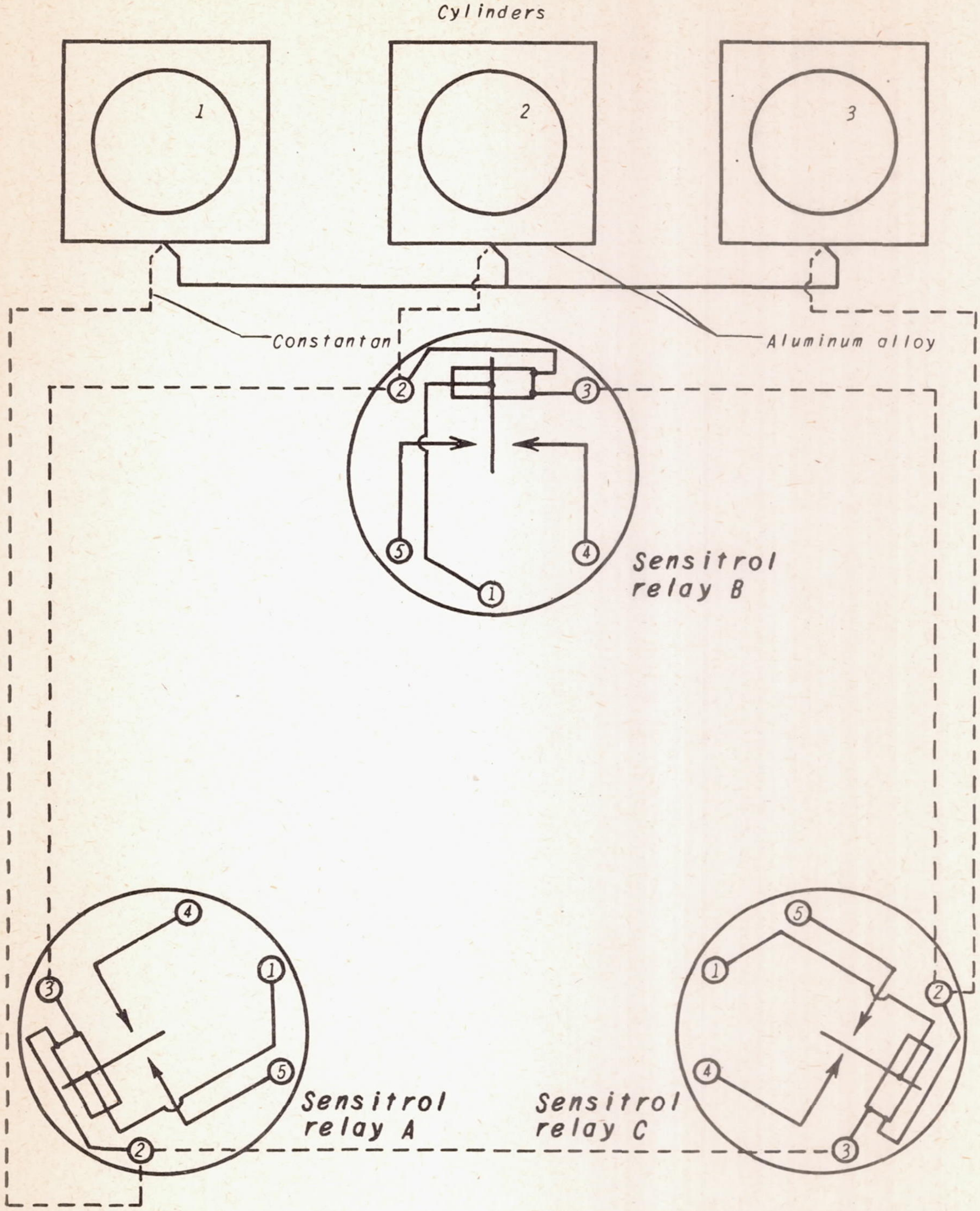
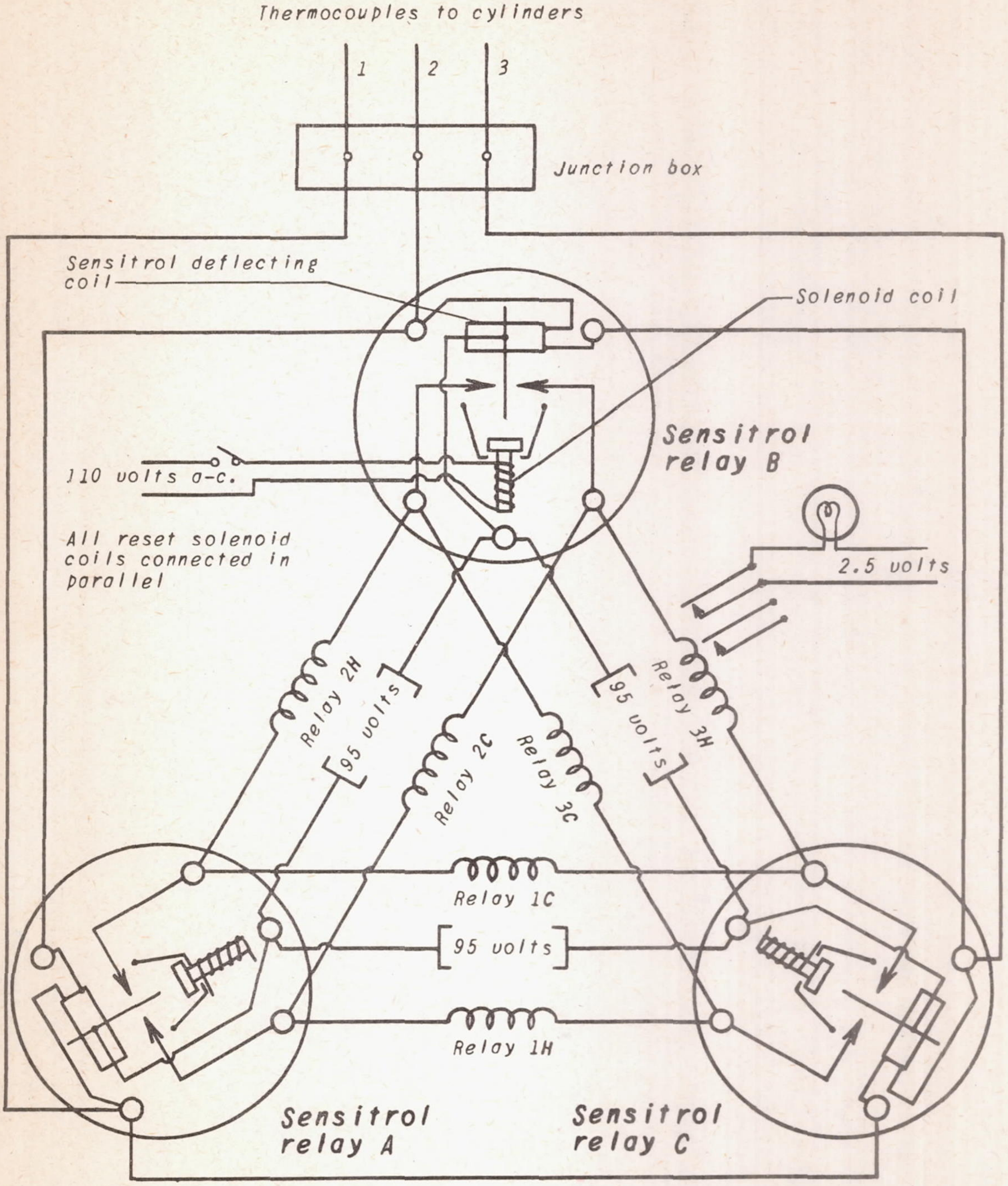
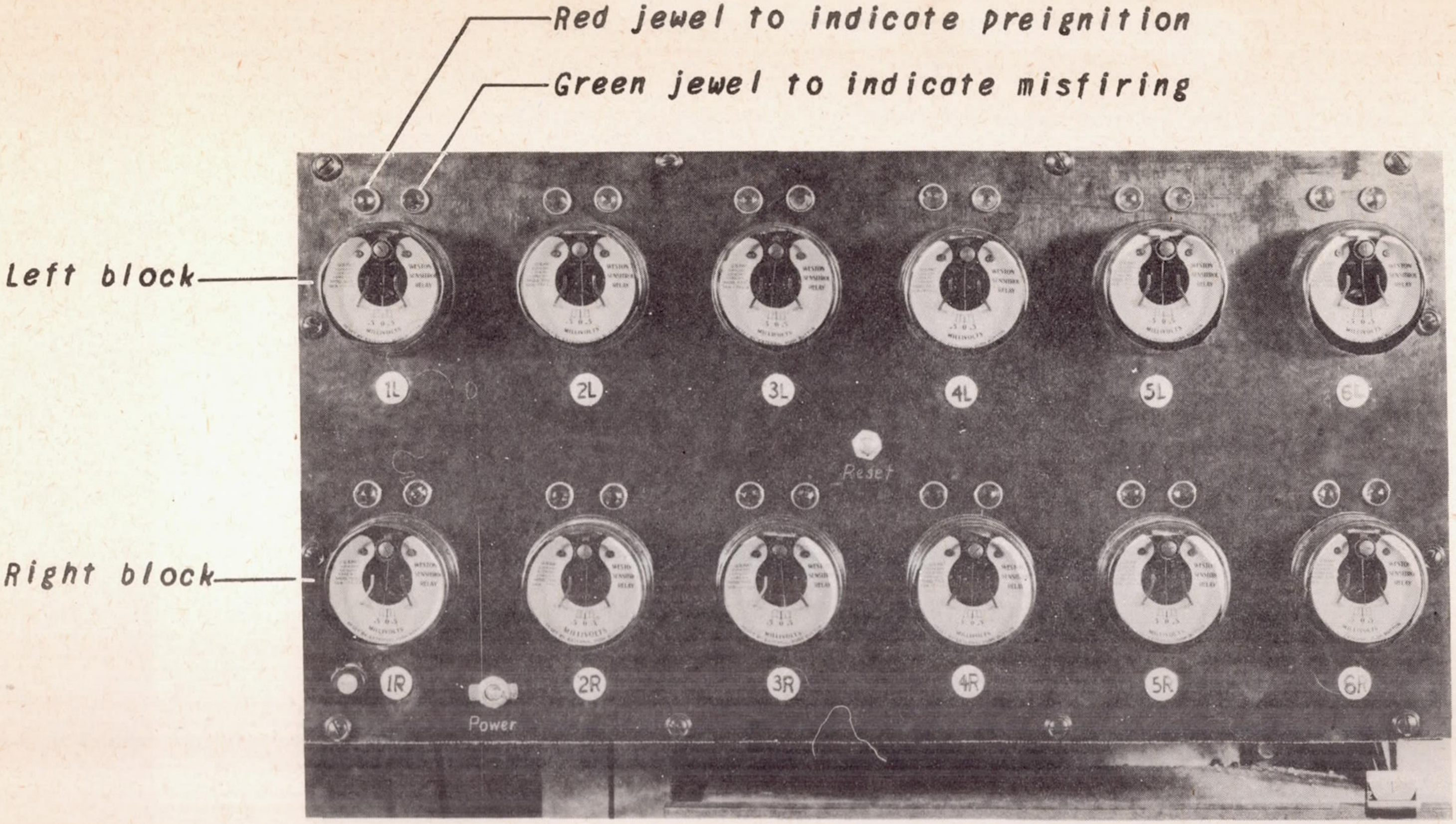


Figure 2. - Simplified circuit diagram of preignition indicator.



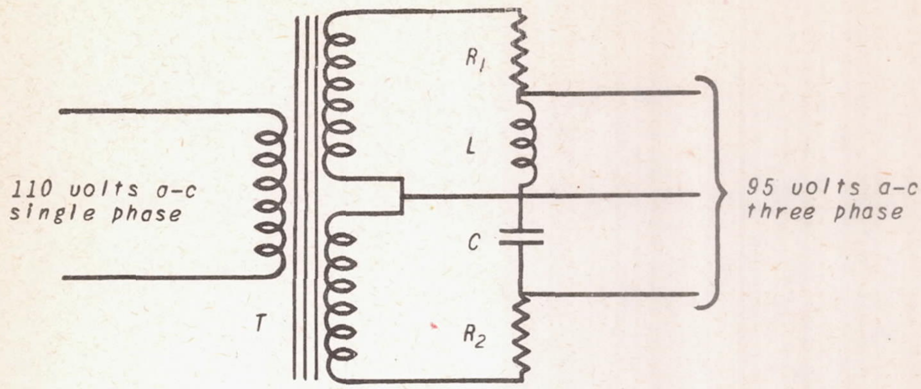
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 3. - Actual diagram of preignition indicator.



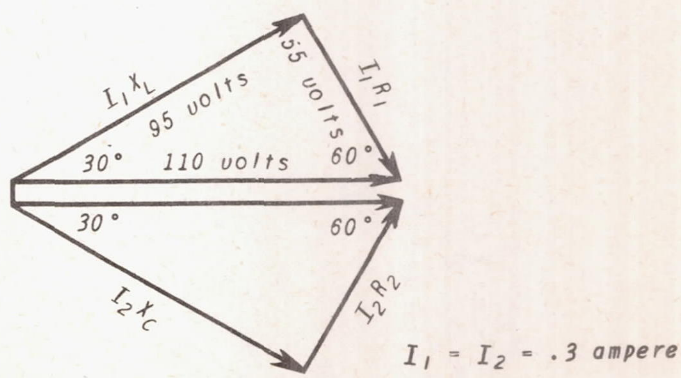
NACA
C-5343
6-15-44

Figure 4. - Preignition-indicator panel for use with Allison V-1710 engine.



R_1, R_2. 183 ohms
L .84 henry
C 8.4 microfarad
T 1:1 ratio isolation transformer
with two secondary windings

Figure 5. - Power supply for preignition indicator.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 6. - Vector diagram for power supply.