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DILUTION OF EXHAUST-GAS SAMPLES FROM A MULTICYLINDER ENGINE EQUIPPED WITH AN EXHAUST-GAS COLLECTOR

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DILUTION OF EXHAUST-GAS SAMPLES FROM A MULTICYLINDER ENGINE EQUIPPED WITH AN EXHAUST-GAS COLLECTOR

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INTRODUCTION

The fuel-air ratio at which an engine is operating is one of the important variables affecting engine performance. Measurement of the fuel-air ratio of each cylinder of a multicylinder engine is necessary in mixture-distribution tests, detailed cooling tests, and other types of multicylinder-engine investigations. Because individual fuel-air ratios are generally determined by chemical analysis of the exhaust gas, the accuracy of this method depends to a large degree upon the purity of the exhaust-gas sample.

Inasmuch as multicylinder engines usually employ some type of collector device connecting the exhaust stacks of several cylinders, it is necessary to determine whether accurate samples of the exhaust gas from individual cylinders can be obtained under those conditions. A sample of exhaust gas taken from an individual stack may be contaminated in two ways: (1) If a collector is used, the sample from a certain stack may not be representative of the exhaust from that cylinder because of infiltration of gases from adjacent stacks; and (2) if individual stacks are used or if there are leaks in the sampling lines, the exhaust-gas samples may be diluted with air because of the breathing action of the engine.

The present investigation was undertaken at the Cleveland laboratory of the NACA to determine the effect of a collector ring on exhaust-gas sampling.

APPARATUS AND TESTS

Engine and exhaust-gas-sampling equipment. - A Pratt & Whitney R-2800-39 engine fitted with a Martin B-26B cowling and installed in a test cell (fig. 1) was used during the exhaust-gas-dilution tests. The R-2800-39 is an 18-cylinder, two-row radial, air-cooled engine with a normal rating of 1500 brake horsepower at an engine speed of 2400 rpm. The exhaust-gas collector ring (fig. 2) consists of two parts, each receiving the exhaust from nine cylinders. Because of this symmetrical arrangement, dilution tests were necessary for only half the exhaust collector. By means of an ignition short-circuiting system, firing of any cylinder or group of cylinders could be prevented.

Samples of exhaust gas were obtained from each cylinder through 1/4-inch stainless-steel tubes located in the stack immediately downstream of the exhaust port. (See fig. 3.) The intake end of each tube, flattened to form a slot-type orifice 0.01 inch wide, was placed to receive the full impact pressure of the gas issuing from the exhaust port, as recommended in reference 1. Copper tubes 30 feet long and 1/4 inch in diameter led from the sampling lines to a set of water traps provided to remove condensate from the exhaust gas. The tubes were continued to the sampling bottles by plastic tubes 15 feet in length. The sampling setup is shown schematically in figure 4.

Simultaneous determinations of the exhaust-gas samples were made on all cylinders. The samples were collected in glass bottles and analyzed immediately afterward. The tests showed that the gas pressure built up in the stack by use of the collector ring, in addition to the impact pressure of the exhaust gas, was sufficiently high under normal operating conditions to force the gas through the sampling lines and pipettes at a satisfactory rate. Air-free samples of exhaust gas were obtained by allowing the gas to flow through the pipettes for about 5 minutes. This self-scavenging method proved to be much more satisfactory than either the liquid-displacement or the evacuated-pipette method because it required less attention and manipulation and provided air-free samples under all test conditions.

Test method. - When an engine operates at rich fuel-air mixtures, no oxygen should be found in the exhaust gas. If one of the cylinders is not firing, the exhaust from that cylinder should contain no carbon dioxide but only a mixture of air and unburned fuel vapor. Dilution in this case would be evidenced in either of two ways: by the presence of oxygen in the exhaust from the adjacent cylinders or by the presence of carbon dioxide in the exhaust from the cylinder not firing. If the fuel-air mixture from the nonfiring cylinder contaminated the exhaust gas from the adjacent cylinders, appreciable amounts of oxygen should be found in the exhaust gas from those cylinders; the percentage oxygen would be a direct indication of the amount of dilution. On the other hand, if the exhaust from the cylinder not firing is diluted with gas from the collector ring, it should contain a definite percentage of carbon dioxide.

Accordingly, the following test procedure was used. With all cylinders firing, the exhaust gas from each stack was analyzed for both carbon dioxide and oxygen. Then, with engine conditions held constant, the ignition of each cylinder was in turn short-circuited and the exhaust from all cylinders analyzed again. The exhaust gas from the nonfiring cylinder was analyzed for only carbon dioxide, whereas the exhaust from the other cylinders was analyzed for both carbon dioxide and oxygen.

Tests were conducted at engine speeds varying from 1600 to 2400 rpm and at powers ranging from 800 to 1400 brake horsepower. No attempt was made to vary the back pressure. The static pressure in the exhaust stack varied slightly with engine power; the average pressure was approximately 1 inch of mercury gage.

RESULTS AND DISCUSSION

The results of tests to determine the percentage by volume of exhaust gas from the collector ring in the samples of fuel-air mixture from the cylinder not firing are presented for several engine powers and speeds in the following table:

Cylinder not firing	800 bhp		1100 bhp		1400 bhp
	1600 rpm	2400 rpm	2000 rpm	2400 rpm	2400 rpm
2	1.1	3.1	1.0	2.3	0
3	2.3	4.1	0	2.3	1.4
4	0	2.0	2.0	1.1	1.4
5	2.3	2.0	1.0	1.1	2.7
6	2.3	1.0	1.0	1.1	0
7	2.3	1.0	1.0	1.1	1.4
8	0	1.0	2.0	0	1.4
9	4.5	2.0	2.0	1.1	1.4
10	2.3	1.0	1.0	2.3	0

Calculations of the percentage dilution were based on the assumption that the exhaust from a cylinder which is firing properly should contain no oxygen. The fact that small amounts of oxygen are often found in the exhaust even at rich mixtures made the tests very severe. Despite the severity of these tests, the maximum value of dilution was less than 5 percent; the average value was approximately 2 percent.

The results of tests to determine the percentage of air from the nonfiring cylinder in samples of exhaust gas from adjacent cylinders are shown for two sets of engine conditions in the following table:

Cylinder ↓ / Cylinder not firing →	2	3	4	5	6	7	8	9	10
Engine power, 800 bhp; engine speed, 1600 rpm									
2	---	0	0.5	0	0	1.0	1.0	0	0.5
3	1.0	---	1.4	0	0	0	0	0	0
4	1.0	0	---	2.4	1.0	.5	1.4	1.0	0
5	0	0	0	---	.5	0	0	.5	.5
6	0	.5	1.9	2.4	---	3.8	.5	1.0	1.4
7	0	0	1.9	1.9	1.9	---	1.9	1.0	1.4
8	1.0	1.0	0	1.9	0	0	---	0	1.4
9	0	0	.5	0	1.0	0	1.9	---	.5
10	1.0	1.4	.5	0	0	1.9	.5	1.0	---
Engine power, 800 bhp; engine speed, 2400 rpm									
2	---	0	0	0	0	0	0	0	0
3	1.4	---	1.0	0	0	0	1.0	0	0
4	0	.5	---	1.0	0	0	.5	0	0
5	0	0	.5	---	1.0	0	0	0	0
6	0	0	0	0	---	0	0	0	0
7	0	0	1.0	0	0	---	1.0	0	0
8	0	1.0	0	0	0	0	---	0	1.0
9	0	0	0	0	0	0	0	---	0
10	1.9	0	0	1.0	0	1.0	0	0	---

Contamination of the air-gas mixture from the nonfiring cylinder with exhaust from the collector ring was slightly greater than dilution of the exhaust from the various cylinders with air from the nonfiring cylinder. This difference may be explained by the fact that the gas pressure in the stack is lower when the cylinder is being motored than it would be if the cylinder was firing.

An example of the effect of dilution on the determination of the fuel-air ratio follows: It is assumed that the exhaust from cylinder A, operating at a fuel-air ratio of 0.080, is diluted with 5 percent by volume of exhaust gas from cylinder B with a fuel-air ratio of 0.10. For the fuel used during these tests, the exhaust gases would contain 11.2 and 6.9 percent carbon dioxide, respectively, at these fuel-air ratios. The percentage of carbon dioxide actually found in a sample of exhaust gas from cylinder A would be

$$CO_2 = (0.95 \times 11.2) + (0.05 \times 6.9) = 11.0$$

The difference of 0.2 percent carbon dioxide represents a change in fuel-air ratio of approximately 0.001, which is within the limit of accuracy of measurements.

The amount of dilution encountered in these tests was therefore too small to affect the determination of fuel-air ratios. Thus, if proper precautions for sampling are taken, no appreciable error in fuel-air ratio is introduced at low back pressures by the use of an exhaust-gas collector ring instead of individual stacks. Furthermore, the danger of air dilution resulting from the breathing action of the engine is almost entirely eliminated by the use of a collector ring.

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REFERENCE

1. Cook, Harvey A., and Olson, Walter T.: Small-Orifice Tubes for Minimizing Dilution in Exhaust-Gas Samples. NACA ARR, Feb. 1943.

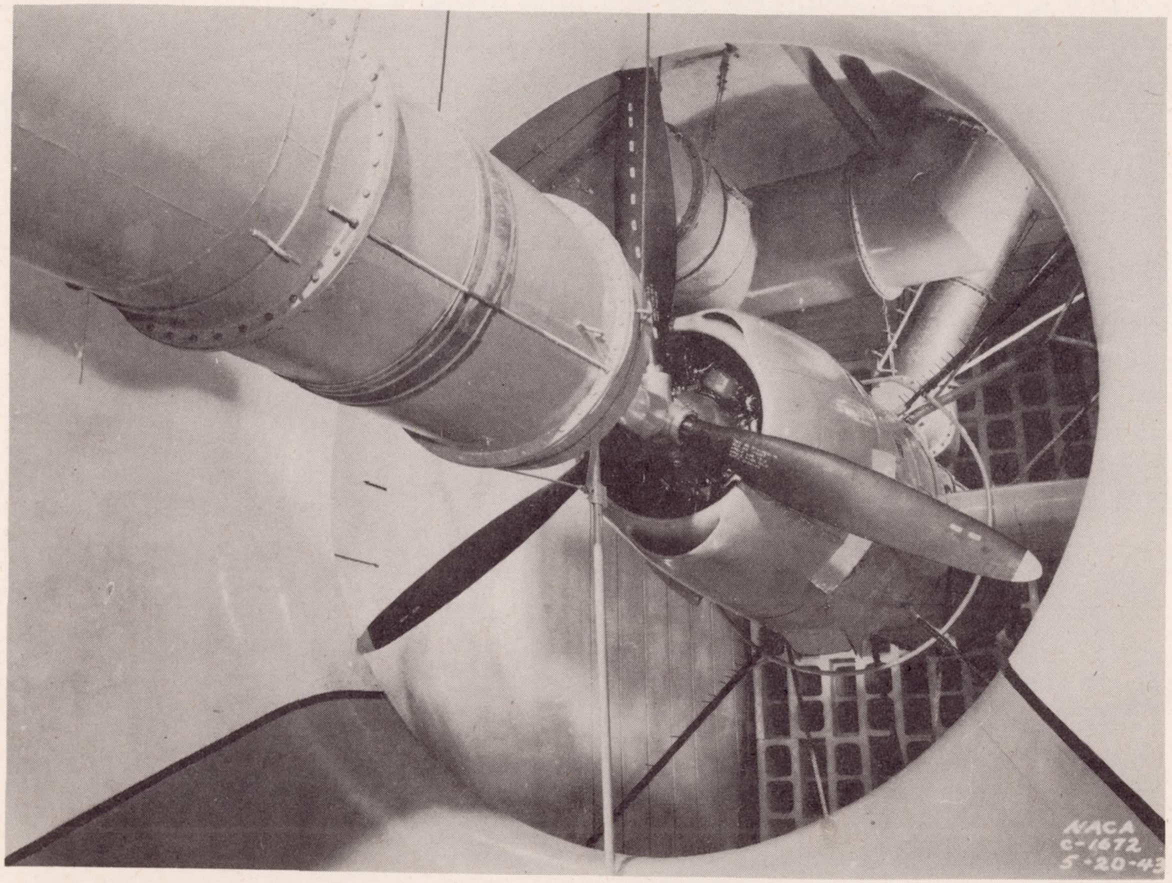

Figure 1. - Test-cell installation of Pratt & Whitney R-2800-39 engine in a Martin B-26B nacelle.

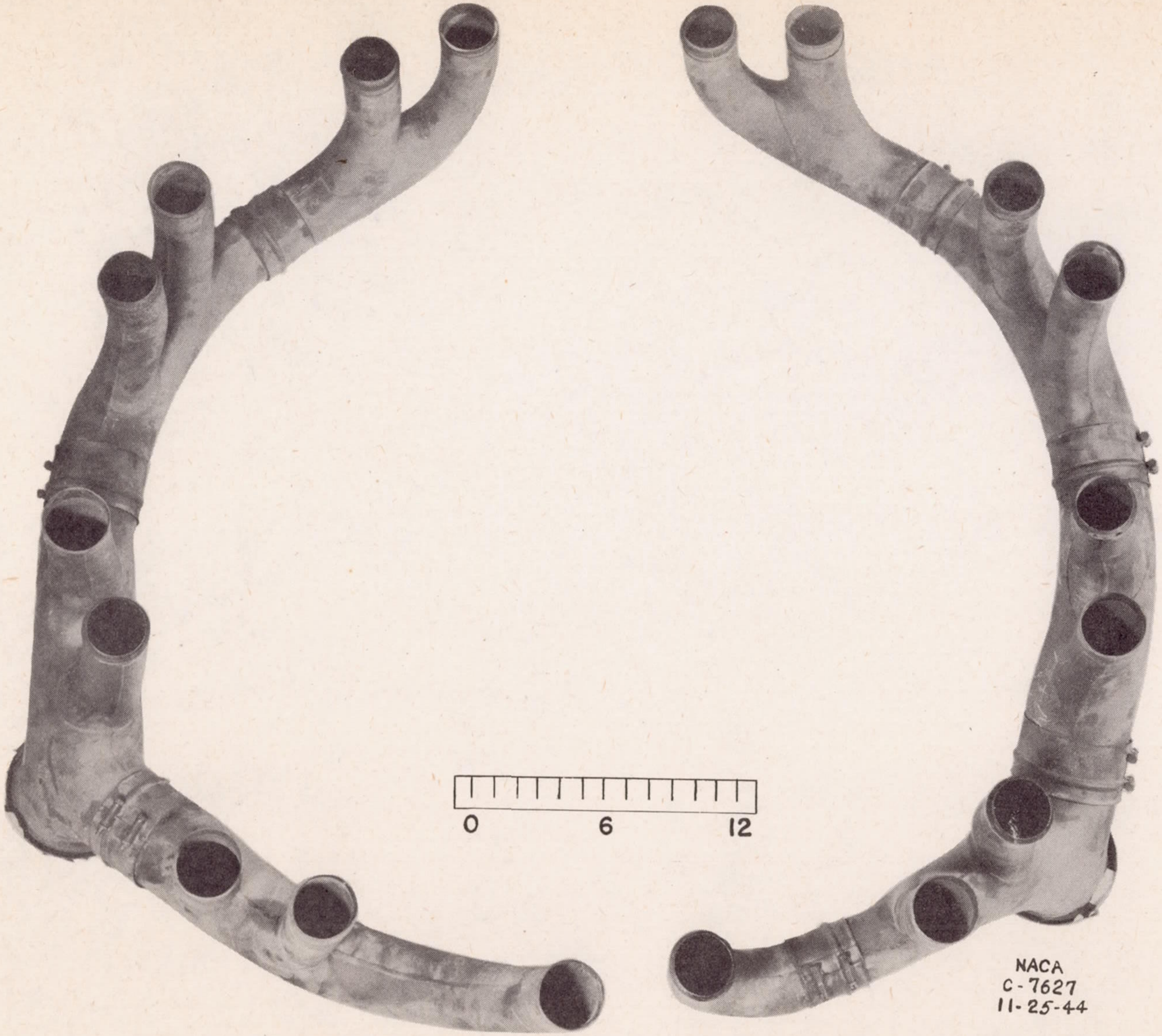

Figure 2. - Exhaust-gas collector ring from a B-26 installation of the Pratt & Whitney R-2800-39 engine.

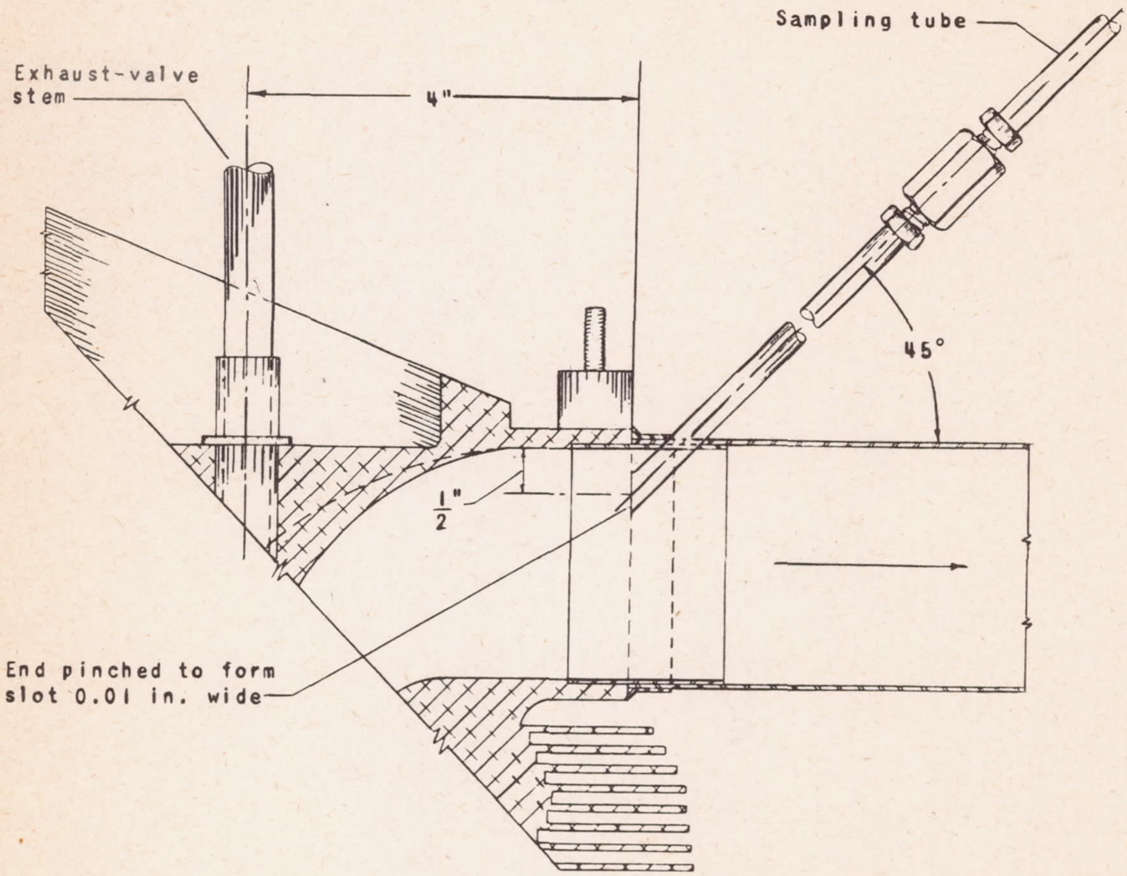

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Figure 3. - Location of exhaust-gas sampling tube on each cylinder.

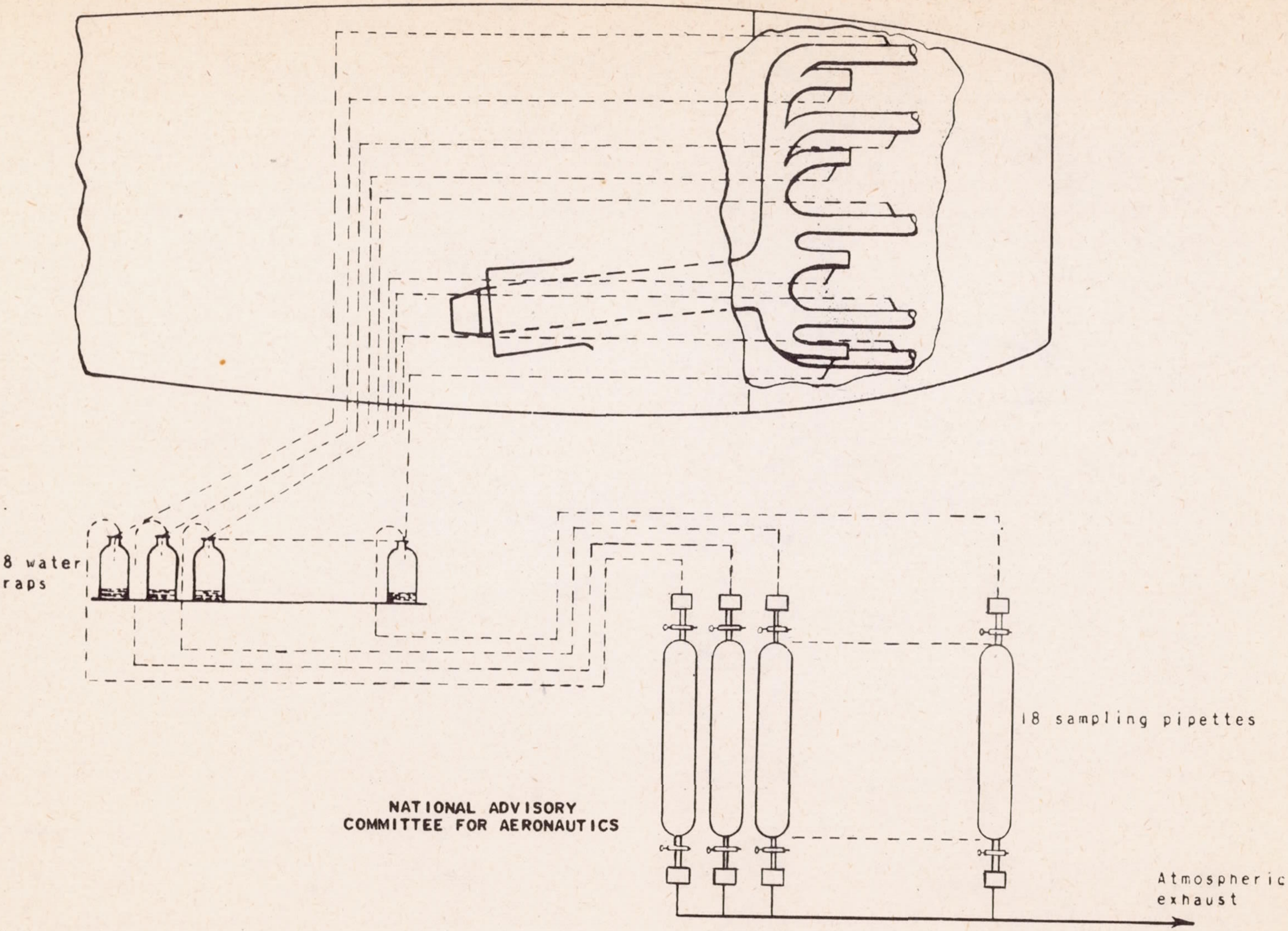

Figure 4. - Schematic diagram of exhaust-gas-sampling system.