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RESEARCH MEMORANDUM

PRELIMINARY EVALUATION OF Hi-Cal-3, HEF-2, AND A SOLUTION OF PENTABORANE - JP-4 FUEL IN A 1/4-SECTOR OF ANNULAR TURBOJET COMBUSTOR

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PRELIMINARY EVALUATION OF Hi-Cal-3, HEF-2, AND A SOLUTION OF PENTABORANE - JP-4 FUEL IN A 1/4 SECTOR OF AN ANNULAR TURBOJET COMBUSTOR*

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Turbojet Engines

SUMMARY

"A brief combustion study of three boron-containing fuels was made in a 1/4 sector of an annular turbojet combustor. The three fuels were Hi-Cal-3, HEF-2 (primarily propylpentaborane), and a solution of 63 percent by weight pentaborane in JP-4 fuel. The combustion efficiencies of the three fuels were between 90 and 95 percent. A photographic comparison of deposits in the combustor is presented."

INTRODUCTION

As part of a program directed toward using boron-containing fuels in aircraft powerplants, new boron compounds are being produced. Some of these compounds are not completely acceptable as aircraft fuels, but may be of use in experimental combustor and engine development work. At the request of the Bureau of Aeronautics, Department of the Navy, three such fuels were tested in a 1/4 sector of an annular turbojet combustor. The results of these tests are presented in this report. Specifically, Hi-Cal-3, HEF-2, and 63 weight percent pentaborane in solution with JP-4 fuel were tested in a combustor initially developed for pentaborane fuel (ref. 1). This combustor was used because it performed reasonably well with fuels having greatly different combustion properties, such as pentaborane and JP-5 fuel. The conditions selected for these tests were the same as those used for evaluation of pentaborane in reference 1. The combustor conditions simulated an altitude of 50,000 feet and a Mach number of 0.8 for a turbojet engine with a compression ratio of 5.2. Combustion efficiency and the amount of deposit in the combustor were determined. The deposits left in the combustor were photographed and weighed. Only single tests (4 min) of each fuel were conducted and no alteration to the combustor or fuel injector was possible because of the limited fuel supplies.

*Title, Unclassified

APPARATUS

Combustor Installation

The combustion air passed through a heat exchanger and a metering orifice into the test installation (fig. 1). The products of combustion discharged into an exhaust system.

The combustor shown in figure 2 is a 1/4-sector of an annular combustor designed to fit the housing diameter and turbine nozzle annulus of a J47 turbojet engine. The general shape of the configuration is similar to the combustor developed in reference 1. The number of slots was changed and additional mixing holes were added. The distribution of the open area listed below was similar to the reference combustor.

Combustor part	Physical area, sq in.	Corrected flow area (flow coefficient assumed), percent
Dome	17.2	26.0
Louvers on outer surface	17.9	20.3
Louvers on inner surface	13.1	14.8
Slots on outer surface	11.7	17.6
Slots on inner surface	11.7	17.6
Holes between mixing slots	3.4	3.7

Fuel Nozzles

The cross section of one of the fuel nozzles is shown in figure 3. The nozzle mixes fuel and air in the tip of the nozzle and atomizes the fuel by discharging it through six ports. The ports are inclined at an angle of 35° from the centerline of the nozzle body. The centerline of the nozzle is normal to the direction of flow through the combustor system. Two sets of five nozzles are used in the 1/4-sector combustor. The test fuels were injected through one set of fuel nozzles. The JP-4 (or gasoline) fuel was introduced through the other set. The fuel nozzles were arranged so that test fuel and JP-4 were introduced alternately around the combustor.

Fuel System

The fuel and atomizing-air systems are shown schematically in figure 4. JP fuel was used to flush the test fuel lines and nozzles immediately before and after the combustion tests.

FUELS

A brief list of fuel properties is presented.

Fuel	Boron, percent by weight	Carbon, percent by weight	Hydrogen, percent by weight	Heat of combustion, Btu/lb	$\frac{\text{lb } B_2O_3}{100,000 \text{ Btu}}$
63 Percent pentaborane, 37 percent JP-4 fuel in solution by weight	54.0	31.7	14.3	25,210	6.87
HEF-2 (propyl-pentaborane)	48.3	37.0	14.3	24,300	6.37
Hi-Cal-3	51.8	33	[a]10.6	22,863	7.25

[a]Based on heat of combustion.

4322

CALCULATION METHODS

Combustion efficiency was determined from the ratio of enthalpy rise across the combustor to the enthalpy rise available from the fuel.

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$$\text{Combustion efficiency, percent} = \frac{(h_{outlet} - h_{inlet})\times 100}{(f/a)(h_v)_{fuel}}$$

where

h_{outlet} enthalpy of (1+f/a) lb of combustion products at combustor outlet temperature (based on B-C-H ratio of the fuel)

h_{inlet} enthalpy of 1 lb of inlet air at inlet-air temperature

$(h_v)_{fuel}$ heating value of the fuel

The reference temperatures at the outlet and inlet were based on the arithmetic average of the individual thermocouples. In these tests the combustor-outlet thermocouples were located 6 inches farther downstream than in reference 1. The additional length improved the temperature distribution and, as a consequence, improved the reliability of the arithmetic average of the outlet temperatures.

4322

INSTRUMENTATION

The instrument stations are shown in figure 1. The arrangement of thermocouples and total-pressure probes is shown in figure 5. Temperatures were measured by bare-wire thermocouples. Fuel flow was measured by a rotating vane flowmeter. Fuel flow rates were also checked by dividing the total fuel used by the test time. Care was taken to keep fuel constant during the test.

PROCEDURE

The 1/4-sector tests were conducted at the following conditions:

Combustor-inlet velocity, ft/sec 70
Combustor-inlet pressure, in. Hg abs 32.3
Combustor-inlet temperature, $^{\circ}F$ 368
Combustor-outlet temperature, $^{\circ}F$ . . . . 1440±40
Air flow, lb/sec 4.5

The combustor was brought to test conditions by using a starting fuel (usually JP-4) in 5 of the 10 nozzles. A small amount of JP-4 fuel was then flushed through the remaining five nozzles, quickly followed by the boron-containing test fuel. The combustor was operated on the test fuel at constant conditions for about 4 minutes. Data were taken at 1-minute intervals. The combustor was shut down immediately after using the test fuel. The deposits in the combustor were then photographed and weighed.

RESULTS AND DISCUSSION

The results of the three fuel tests are given in the following table, which also includes results with two reference fuels, JP-4 and gasoline.

4322

Test	Fuel	Combustor-outlet temperature, °F	Combustion efficiency, percent	Amount of fuel used, lb	Total test time, min	Deposit ratio (a)	Remarks
1	Pentaborane-JP-4 fuel solution	1481	90 to 98	14.3	3.9	0.00103	Apparent efficiency increase during test
2	HEF-2	1440	90	15.8	4.4	.00262	
3	Hi-Cal-3	1389	93	15.6	4.7	.0165	
4	JP-4	1415	90	----	---	-------	Reference test
5	Gasoline	1415	91	----	---	-------	Reference test

[a]Deposit ratio, $\frac{\text{Weight of deposits formed in combustor}}{\text{Weight of boric oxide potentially formed by combustion}}$

The combustion efficiency for all of the fuels tested can be considered to be essentially the same.

Photographs of the combustors after tests of the boron-containing fuels are shown in figures 6, 7, and 8. These photographs in effect reiterate the deposit ratio shown in the preceding table. The amount of boric oxide that was formed in the combustion of each fuel sample (assuming 100-percent combustion efficiency) was 24.6 pounds from HEF-2, 26.2 pounds from Hi-Cal-3, and 24.9 pounds from the pentaborane - JP-4 fuel solution. Of this potential deposit in the combustors, only 0.022 pound was left in the combustor when the pentaborane - JP-4 solution was used. About $2\frac{1}{2}$ times this amount was left when HEF-2 was tested, and 16 times that of the pentaborane - JP-4 solution when Hi-Cal-3 was tested.

The weight of deposits adhering to the side plates, visible in figures 6(b) and 8(b), was not included in the measurements. The side plates used to form the 1/4-sector are not present in a full annular combustor. They are simple plates, not louvered like the inner and outer surfaces of the combustor. Figure 6(b) in particular illustrates the large difference in the amount of deposit adhering to an untreated wall in comparison to an air-filmed (highly louvered) surface.

Some of the clinkers formed in these tests may have been due to sporadic, or "off-design" operation of the fuel nozzles. For example, the type of clinker attached to the thermocouple rake in figure 7(c) is usually associated with poor performance of a fuel nozzle.

The heavy deposits that resulted in the test of Hi-Cal-3 may have been caused by a similar "off-design" operation of all the fuel nozzles. The fuel nozzles used in these tests were developed for use with pentaborane. Pentaborane has a very low viscosity (about 0.5 centistoke) and is very volatile. The viscosity of the Hi-Cal-3 at 77° F is about 14 centistokes. The high viscosity and low volatility of Hi-Cal-3 could easily alter the fuel spray characteristics so that deposits would form rapidly.

4322

Not enough Hi-Cal fuel was available to conduct a fuel nozzle development study. The general course of action used to improve fuel sprays of viscous fuels is: (1) heat the fuel to reduce viscosity, (2) use higher fuel pressures, (3) increase the number and decrease the size of injection points, and (4) in the case of air-atomizing nozzles, increase the amount of atomizing air. Of course, other methods of improving the spray exist but, in general, the fuel must be very stable thermally and be free of entrained solids in order to apply techniques to improve the fuel spray. In short, a fuel as viscous as Hi-Cal-3 could probably be burned to give less deposit in the combustor by improved fuel injectors, if a large amount of the fuel were available for development work and if the fuel were extremely clean and thermally stable.

The deposits present in the tests of HEF-2 and the pentaborane - JP-4 solution appeared to be acceptable for limited engine testing. The deposit characteristics for these fuels could probably be improved by more fuel injector work also, although, on the basis of these short tests, much less effort appears to be involved.

Miscellaneous Observations

The fuel-handling procedures normally used for pentaborane were used with all the test fuels. The only problems in fuel handling were encountered with Hi-Cal-3, for which the fuel flowmeters gave erroneous readings. The rotating vane used as a flow-rate indicator progressively slowed up during the test. It is suspected that some entrained solids fouled the bearings of the flowmeter.

The odors in the exhaust and the water used in the exhaust sprays were much stronger when Hi-Cal-3 was tested than when pentaborane was used. The odor was similar to those associated with the higher hydrides of boron.

CONCLUDING REMARKS

The results of these tests should not be overgeneralized in view of the small quantity of fuel tested.

The three fuels all burned with about the same combustion efficiency.

The pentaborane - JP-4 fuel solution gave the least deposits in the combustor. Similarily, there were very light deposits in the combustor with HEF-2. Hi-Cal-3 produced relatively heavy deposits in the combustor.

4322

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 17, 1956

REFERENCE

1. Kaufman, Warner B., Lezberg, Erwin A., and Breitwieser, Roland: Preliminary Evaluation of Pentaborane in a 1/4-Sector of an Experimental Annular Combustor. NACA RM E56B13, 1956.

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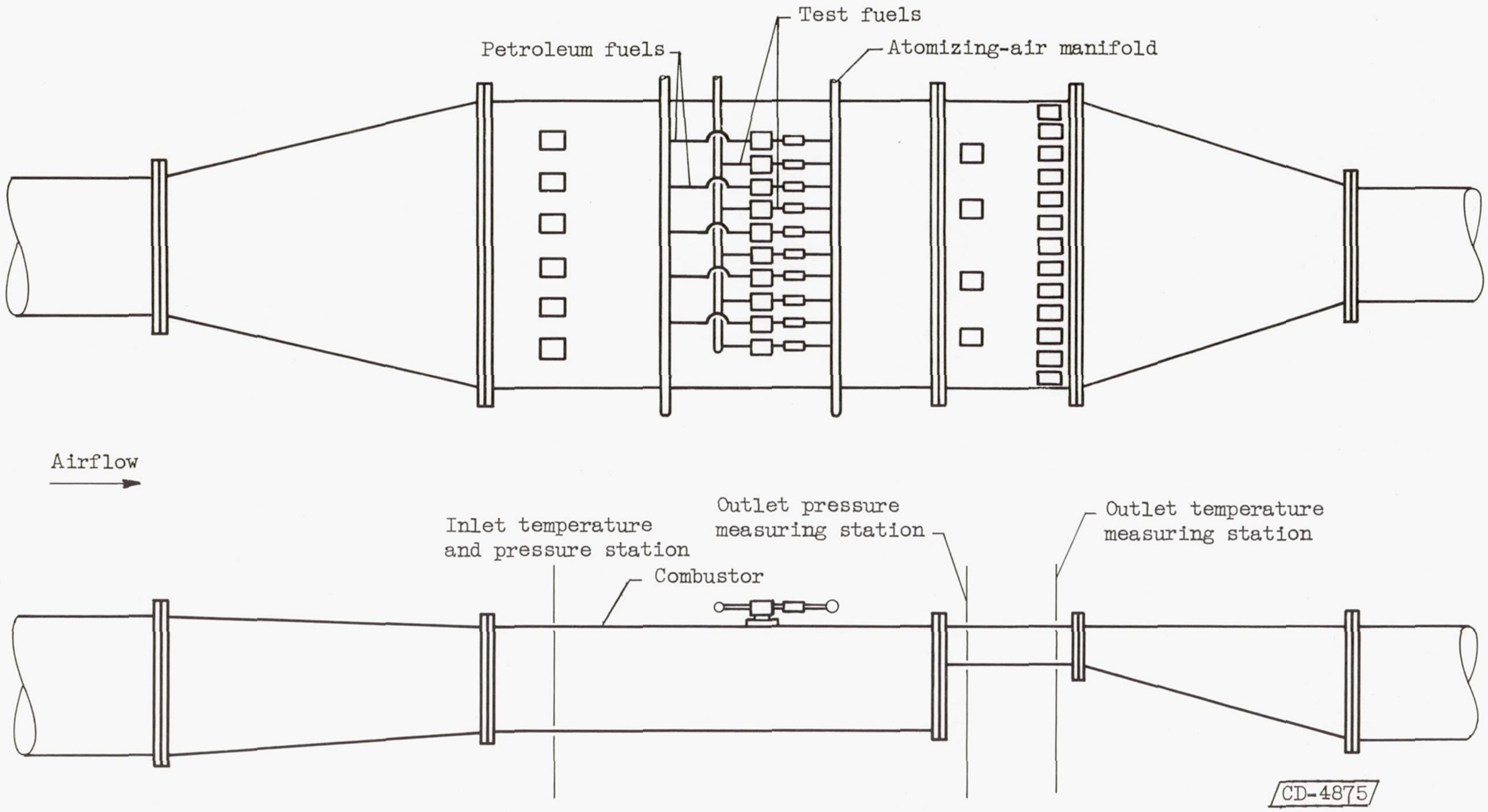

Figure 1. - Schematic diagram of test installation.

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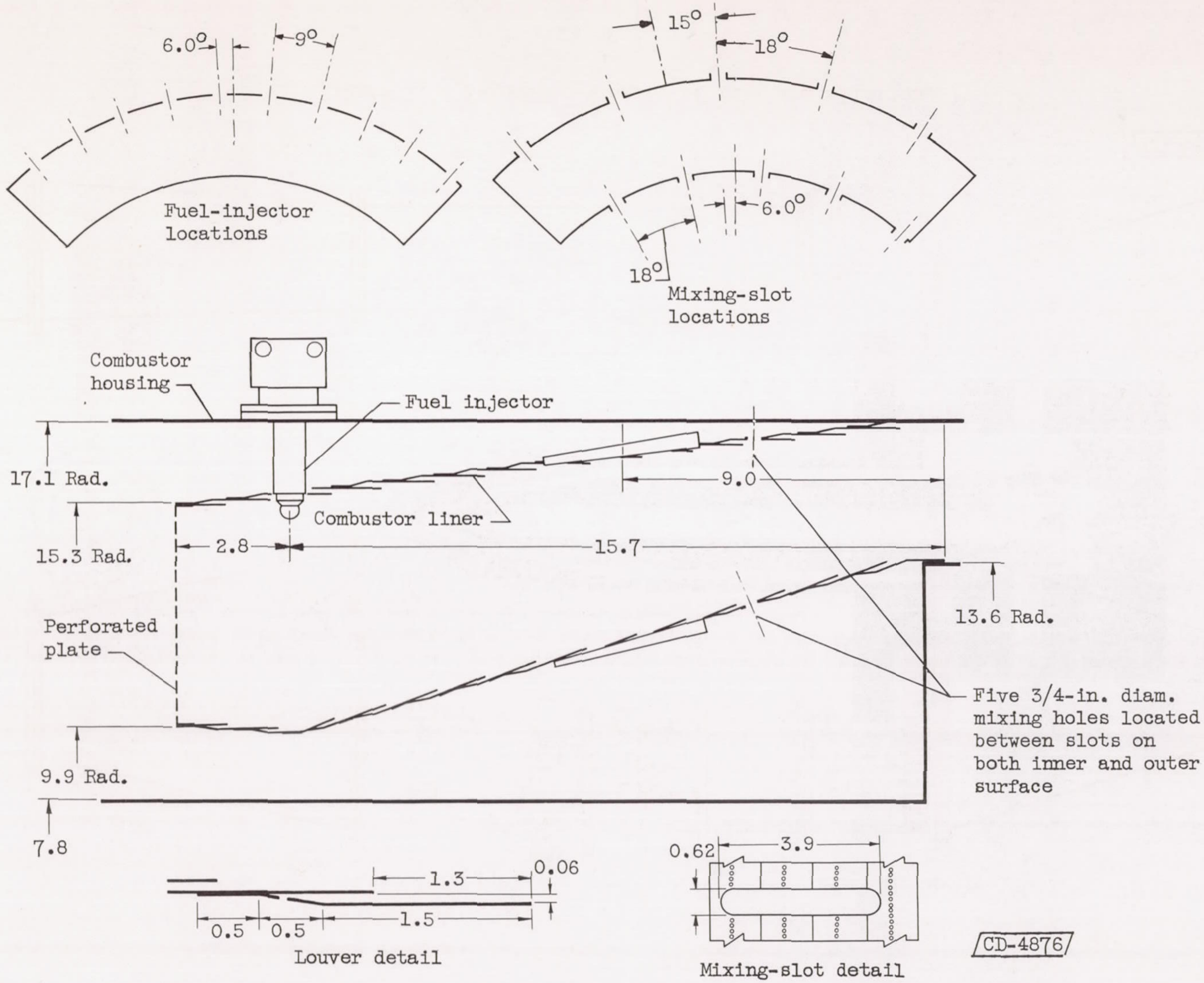

Figure 2. - Diagram of 1/4-sector of annular combustor. (All dimensions in inches.)

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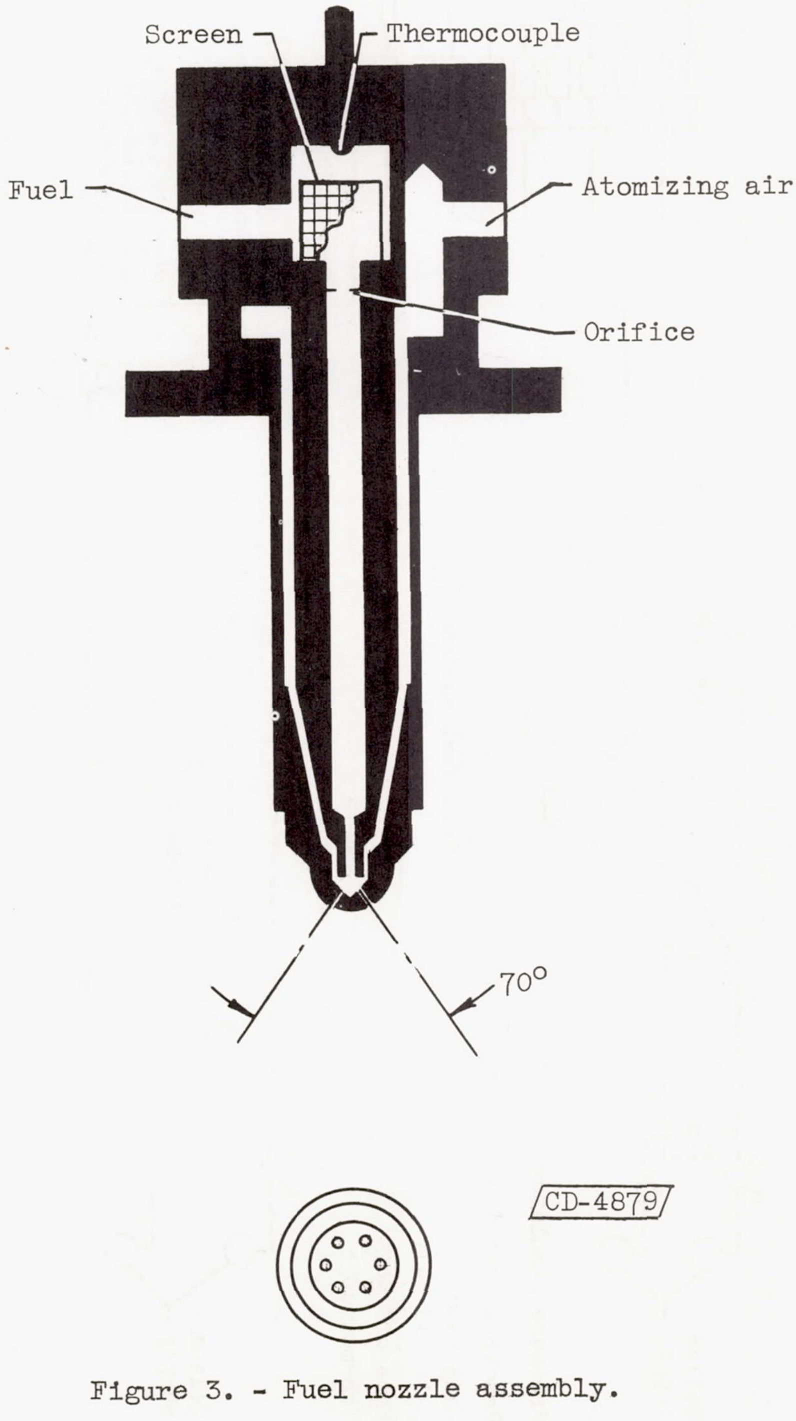


Figure 3. - Fuel nozzle assembly.

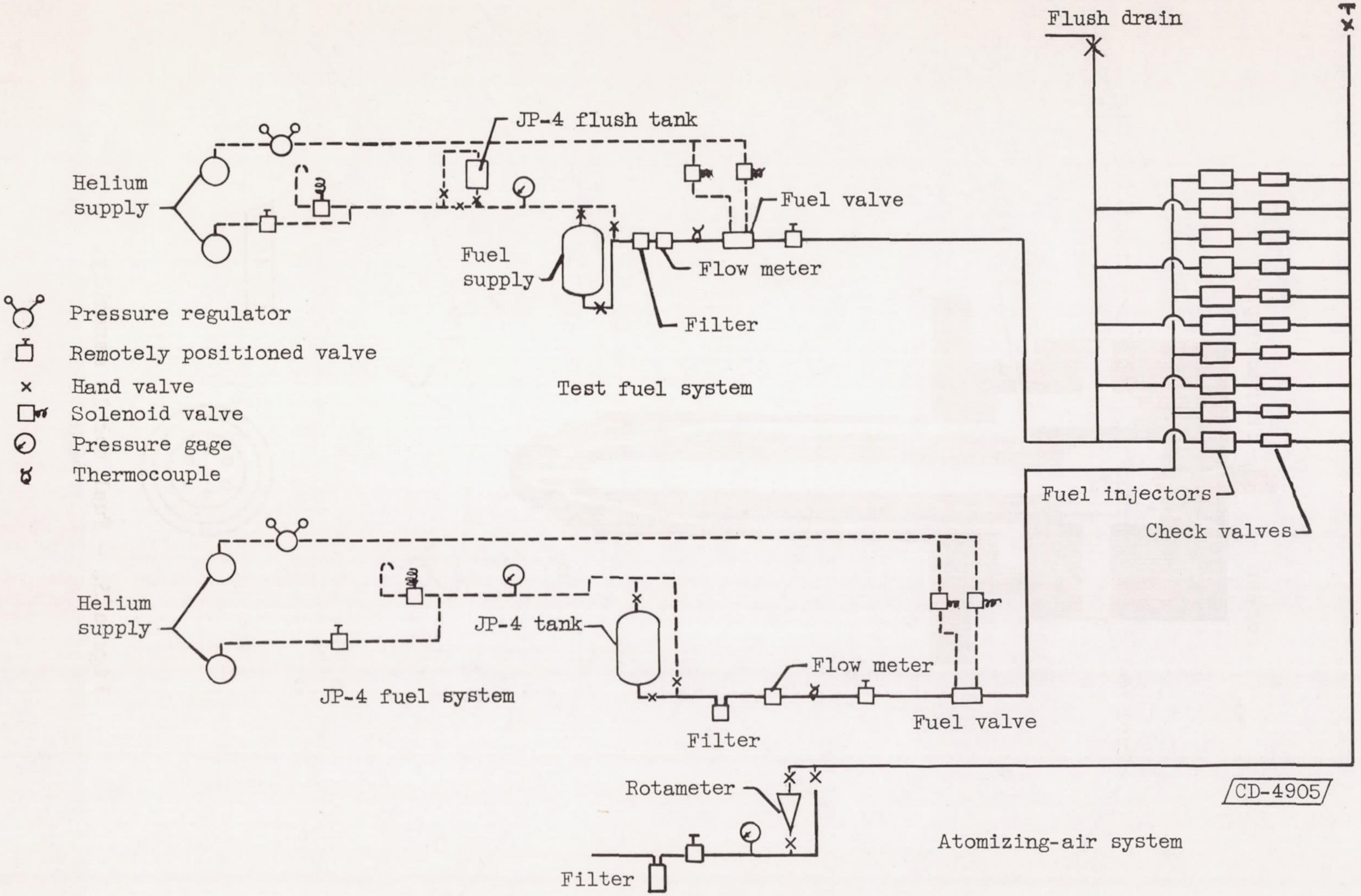


Figure 4. - Fuel and atomizing-air systems.

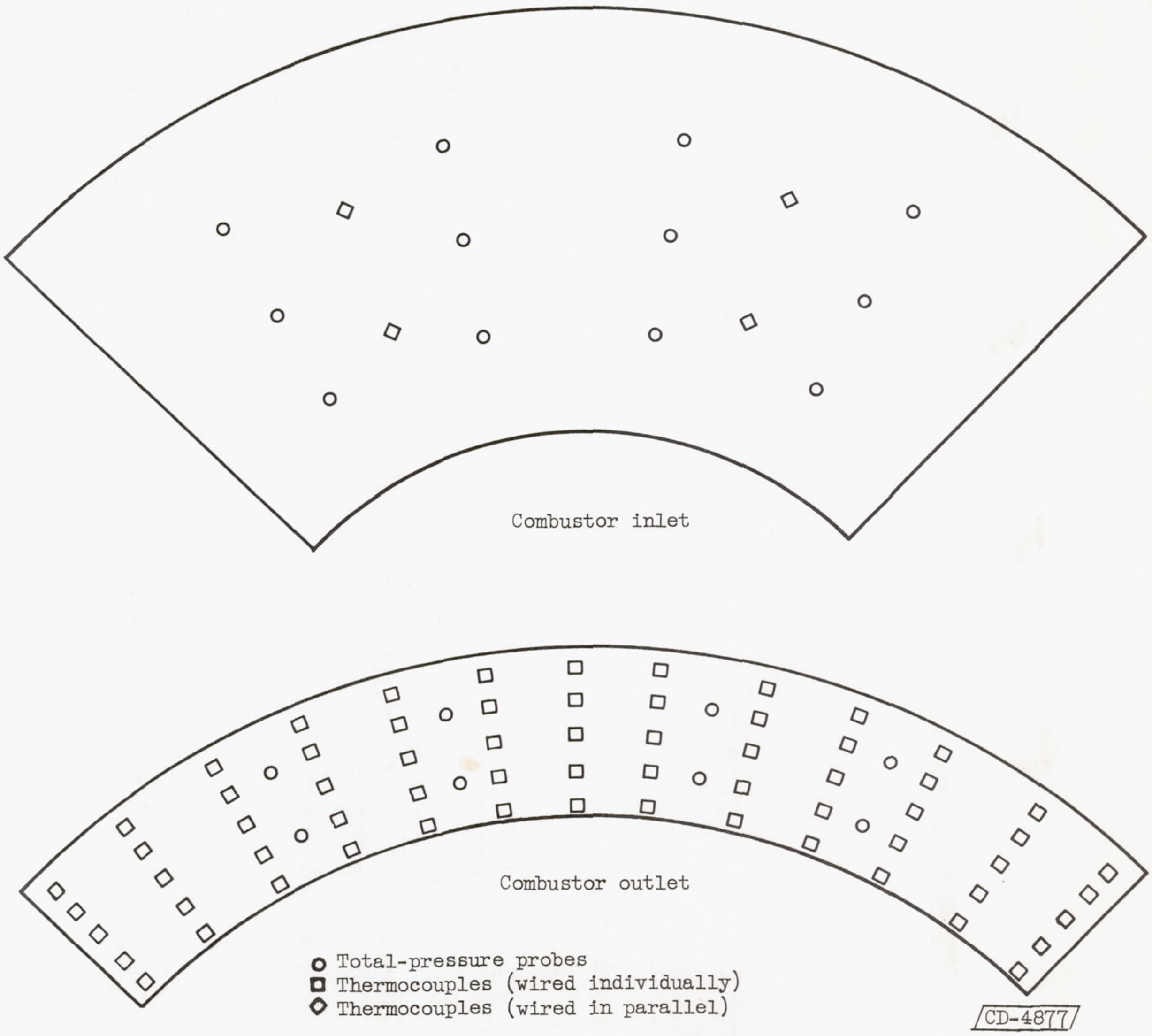
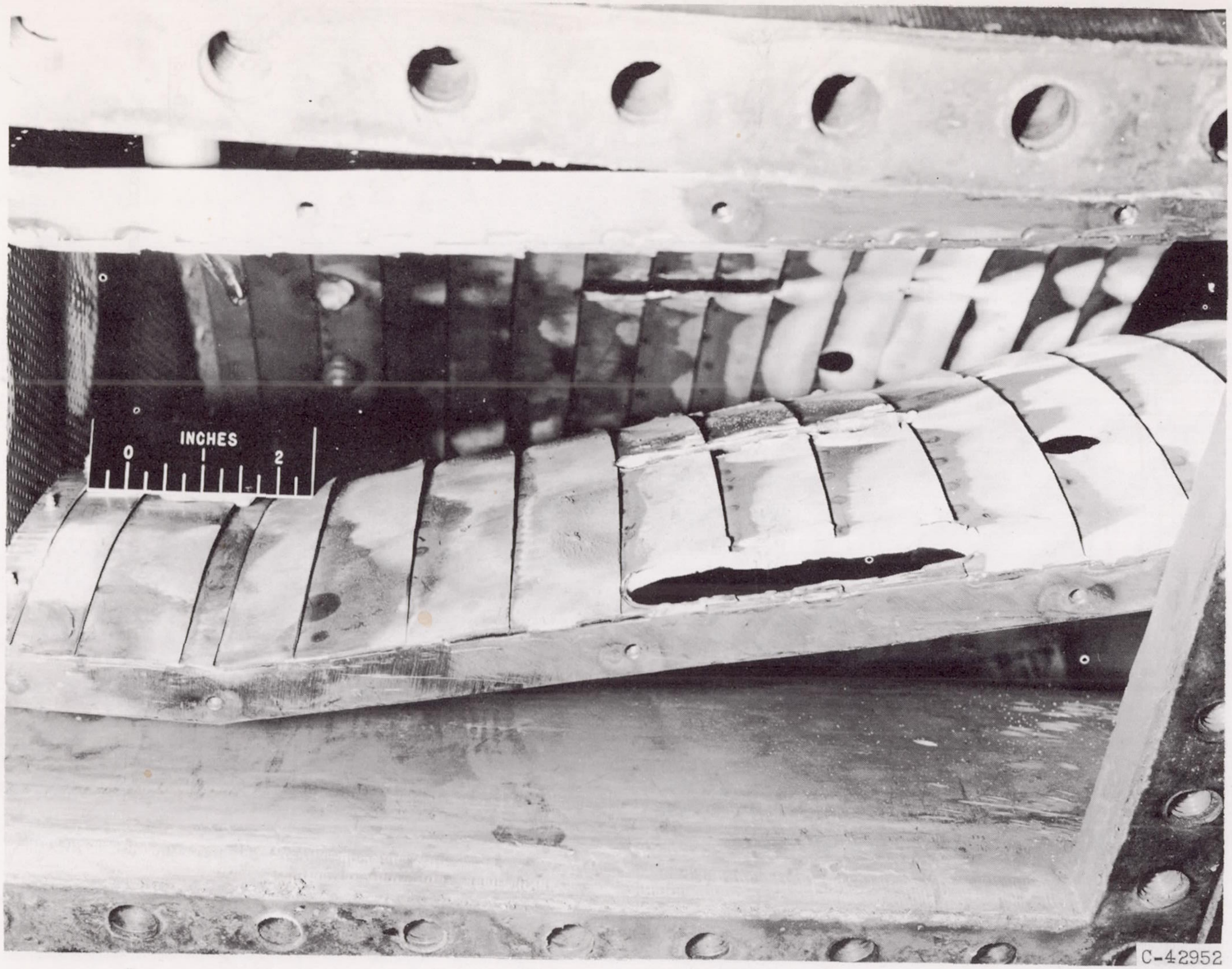
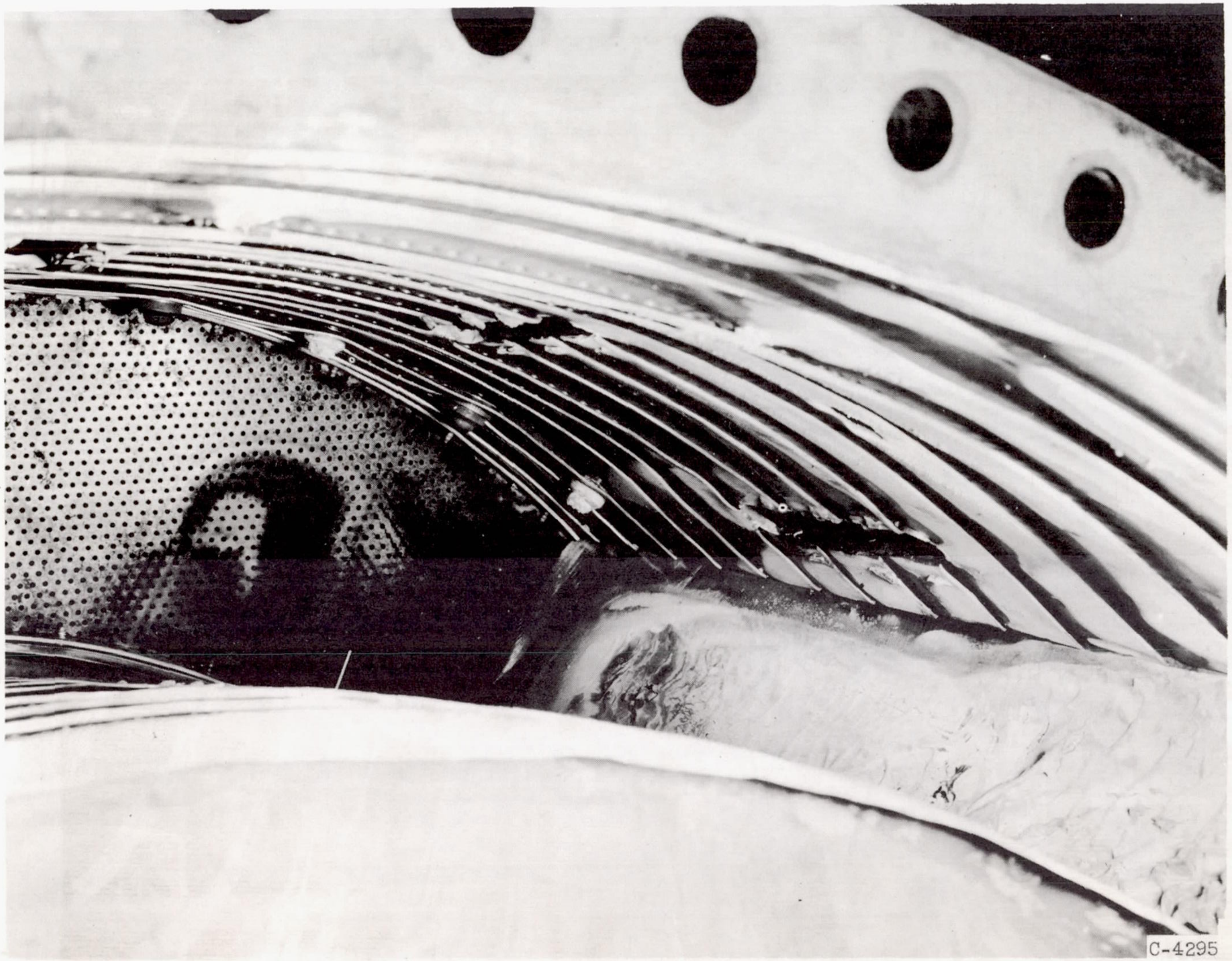


Figure 5. - Location of thermocouples and total-pressure probes.



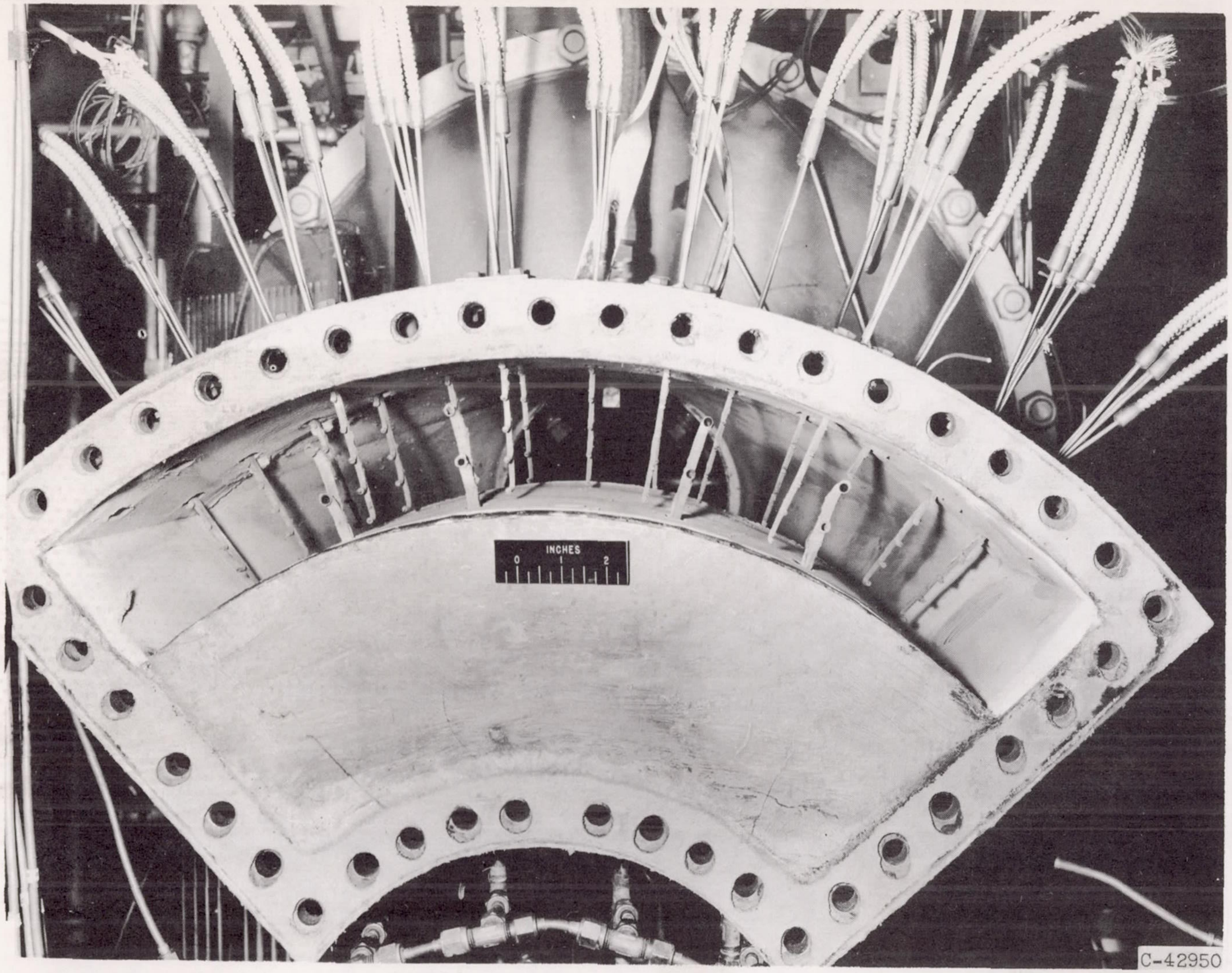
(a) Side view.

Figure 6. - Photographs of combustor after combustion of 14.3 pounds of pentaborane - JP-4 fuel solution.



(b) Rear view.

Figure 6. - Continued. Photographs of combustor after combustion of 14.3 pounds of pentaborane - JP-4 fuel solution.



(c) Instrument section downstream of combustor.

Figure 6. - Concluded. Photographs of combustor after combustion of 14.3 pounds of pentaborane - JP-4 fuel solution.

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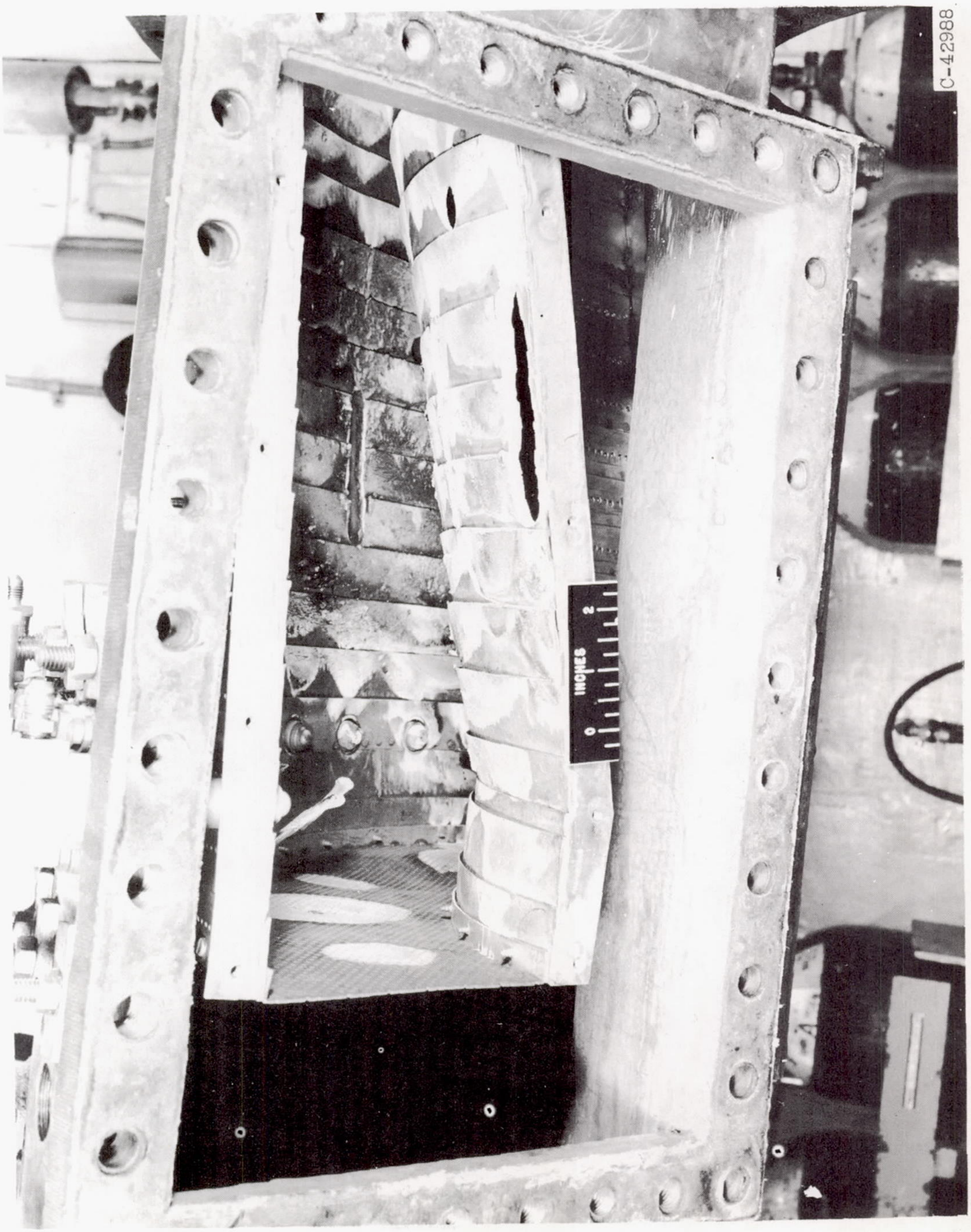
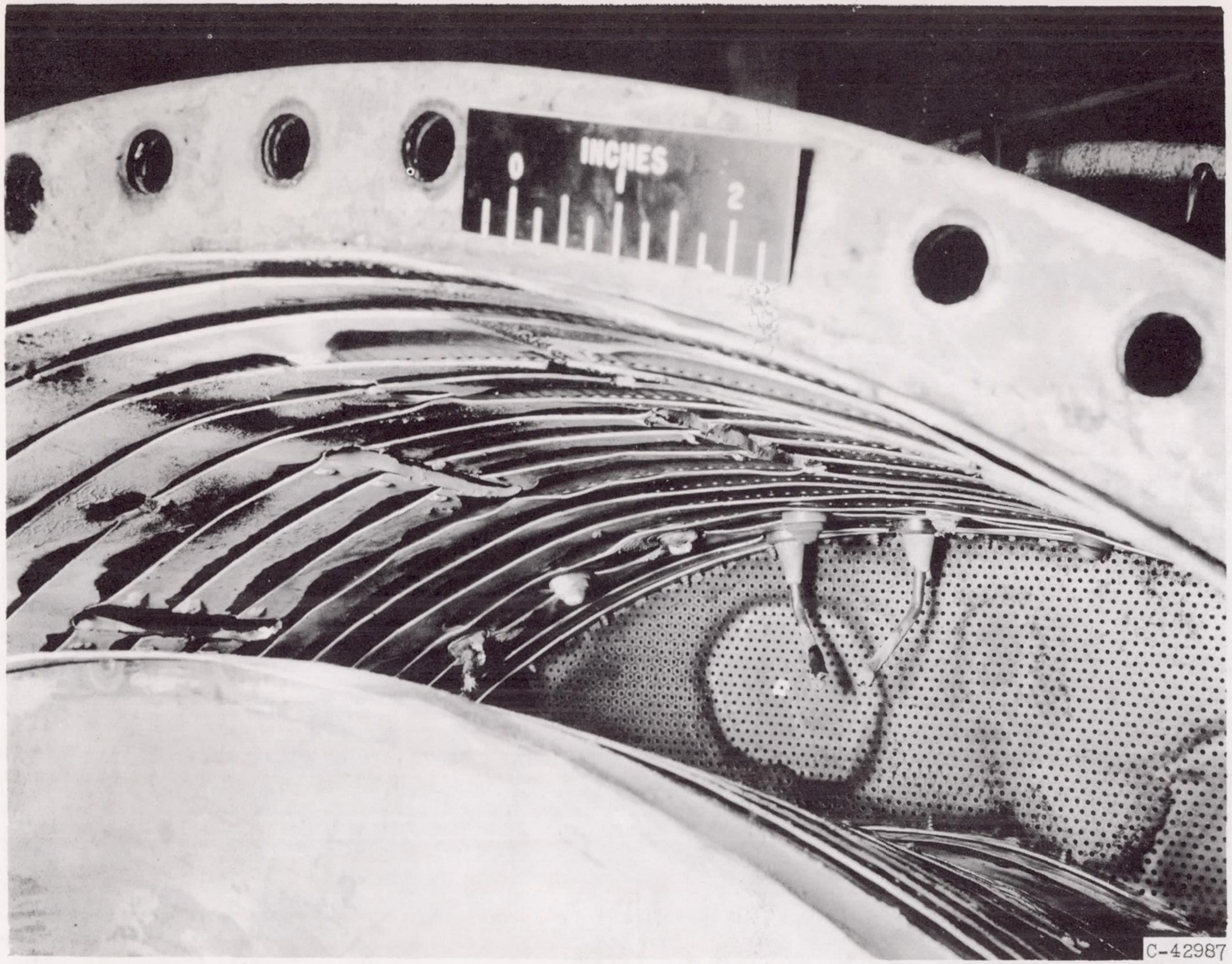


(a) Side view.

Figure 7. - Photographs of combustor after combustion of 15.8 pounds of HEF-2 fuel.



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(b) Rear view.

Figure 7. - Continued. Photographs of combustor after combustion of 15.8 pounds of HEF-2 fuel.

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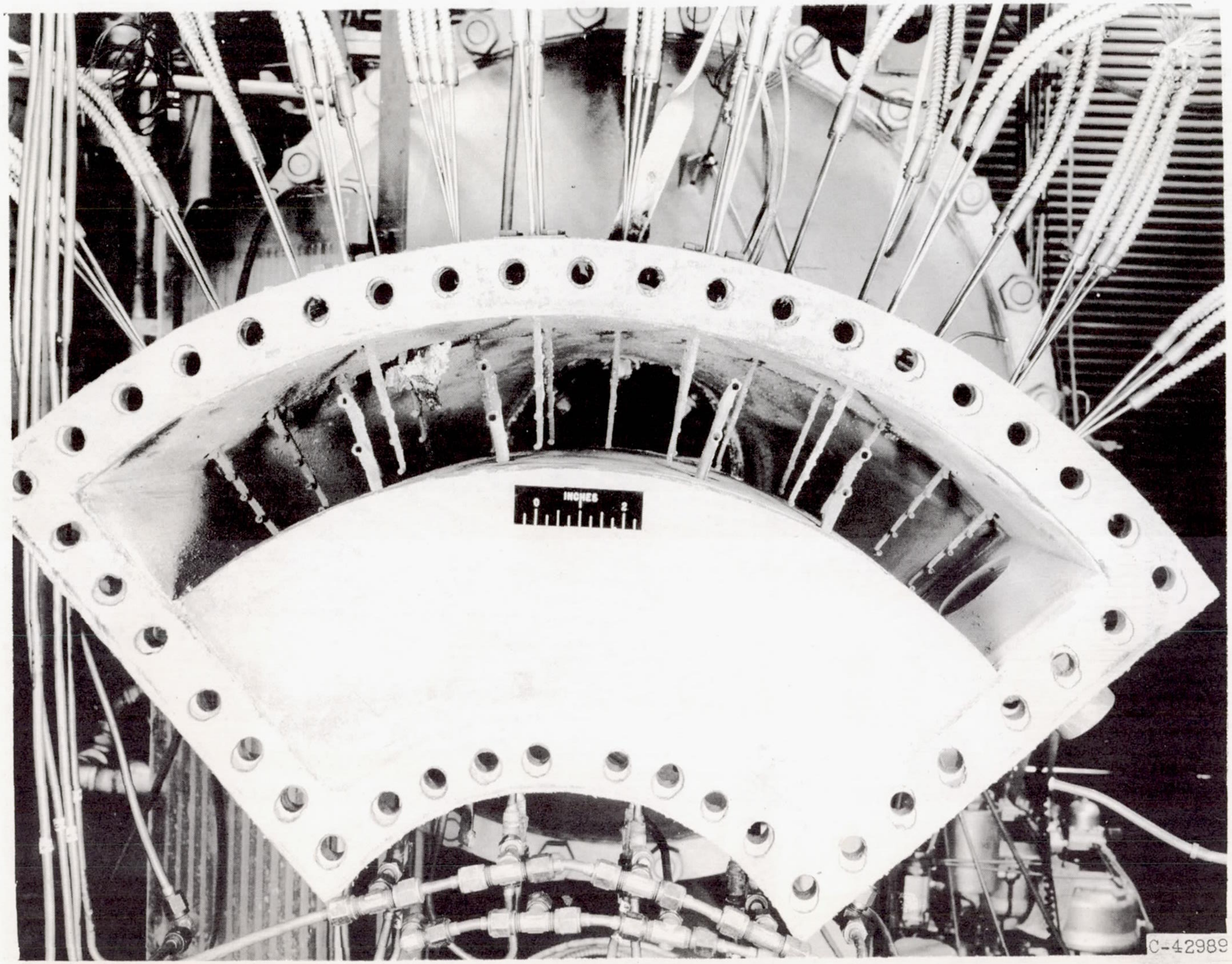

(c) Instrument section downstream of combustor.

Figure 7. - Concluded. Photographs of combustor after combustion of 15.8 pounds of HEF-2 fuel.

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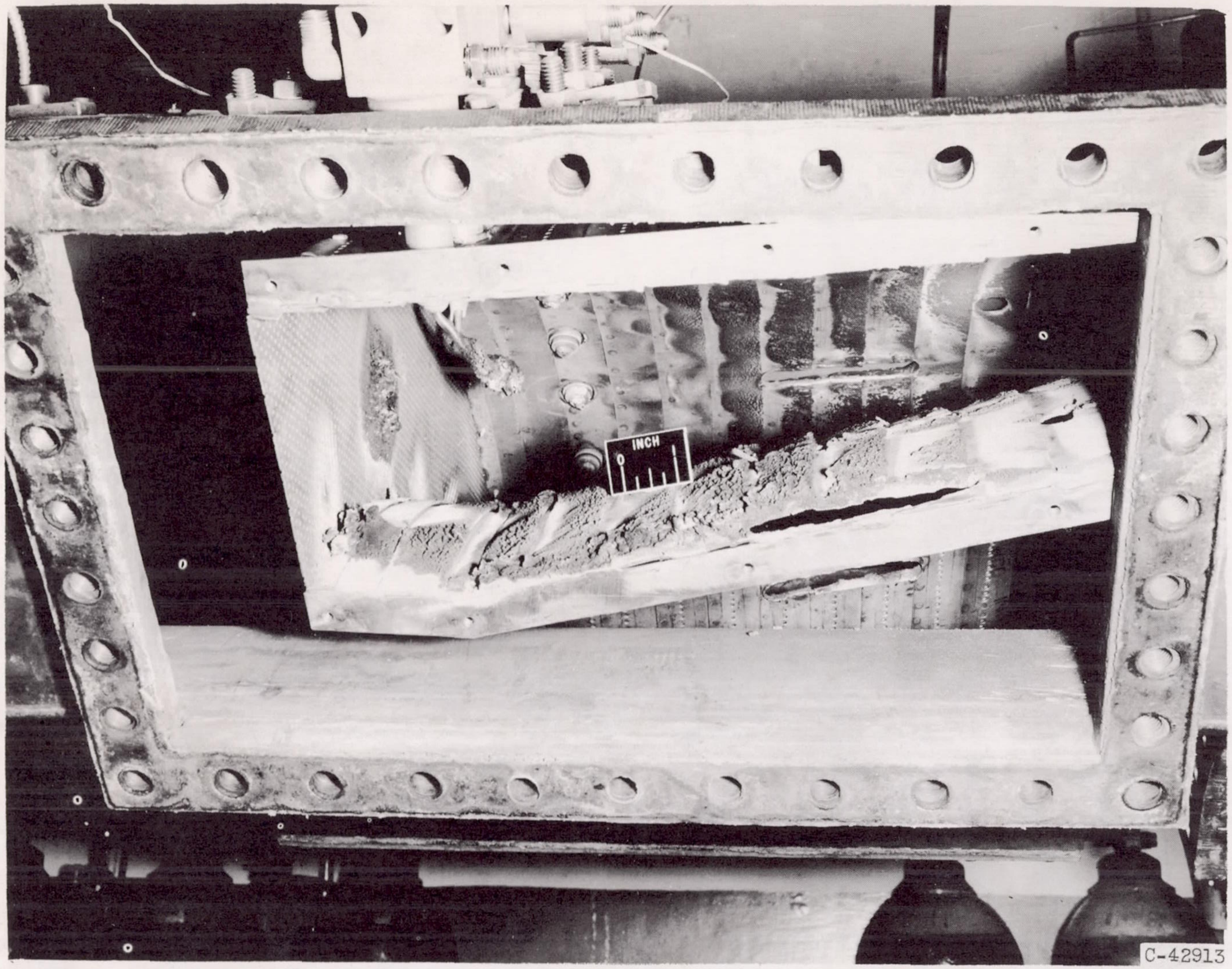

(a) Side view.

Figure 8. - Photographs of combustor after combustion of 15.6 pounds of Hi-Cal-3 fuel.

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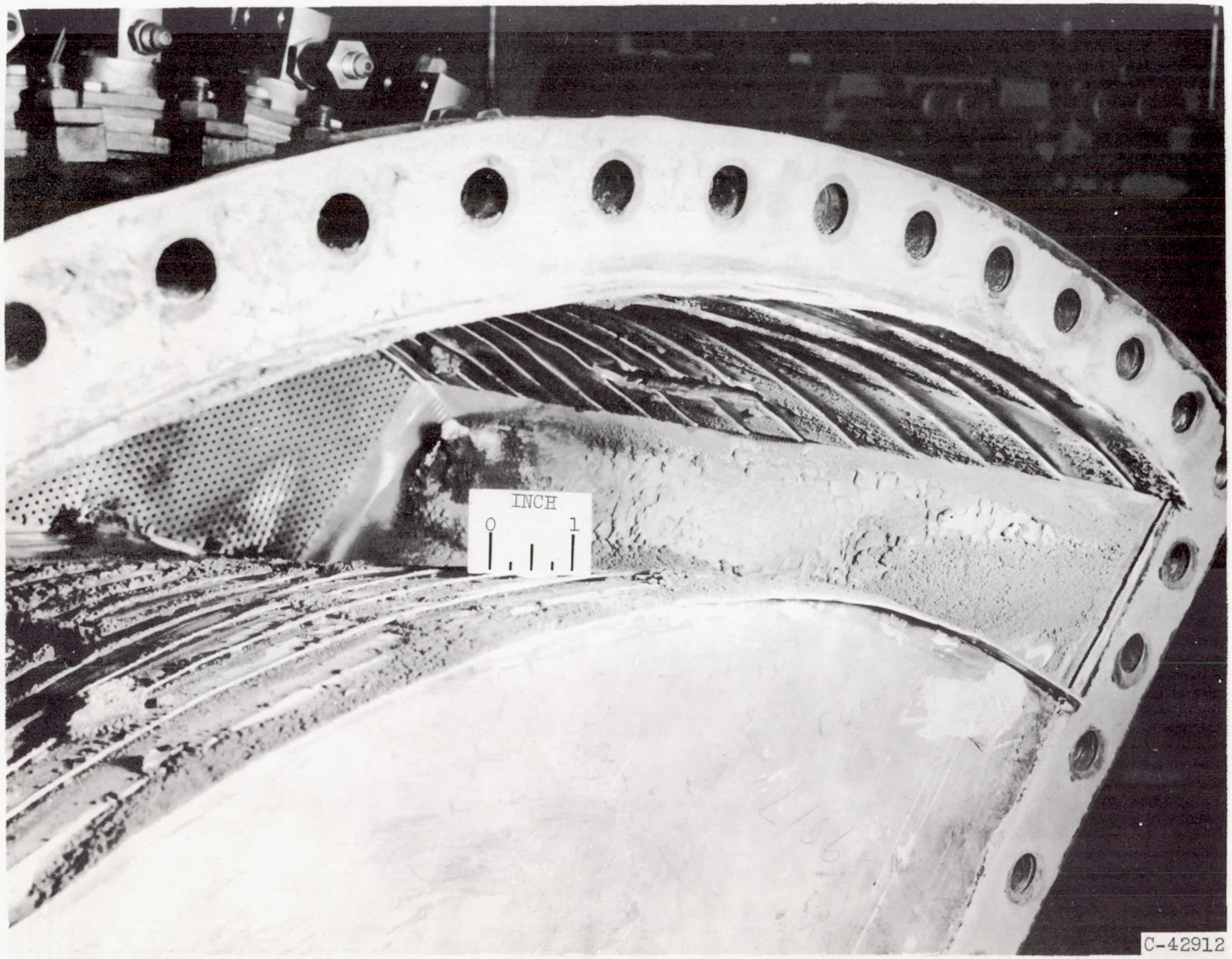

(b) Rear view.

Figure 8. - Continued. Photographs of combustor after combustion of 15.6 pounds of Hi-Cal-3 fuel.

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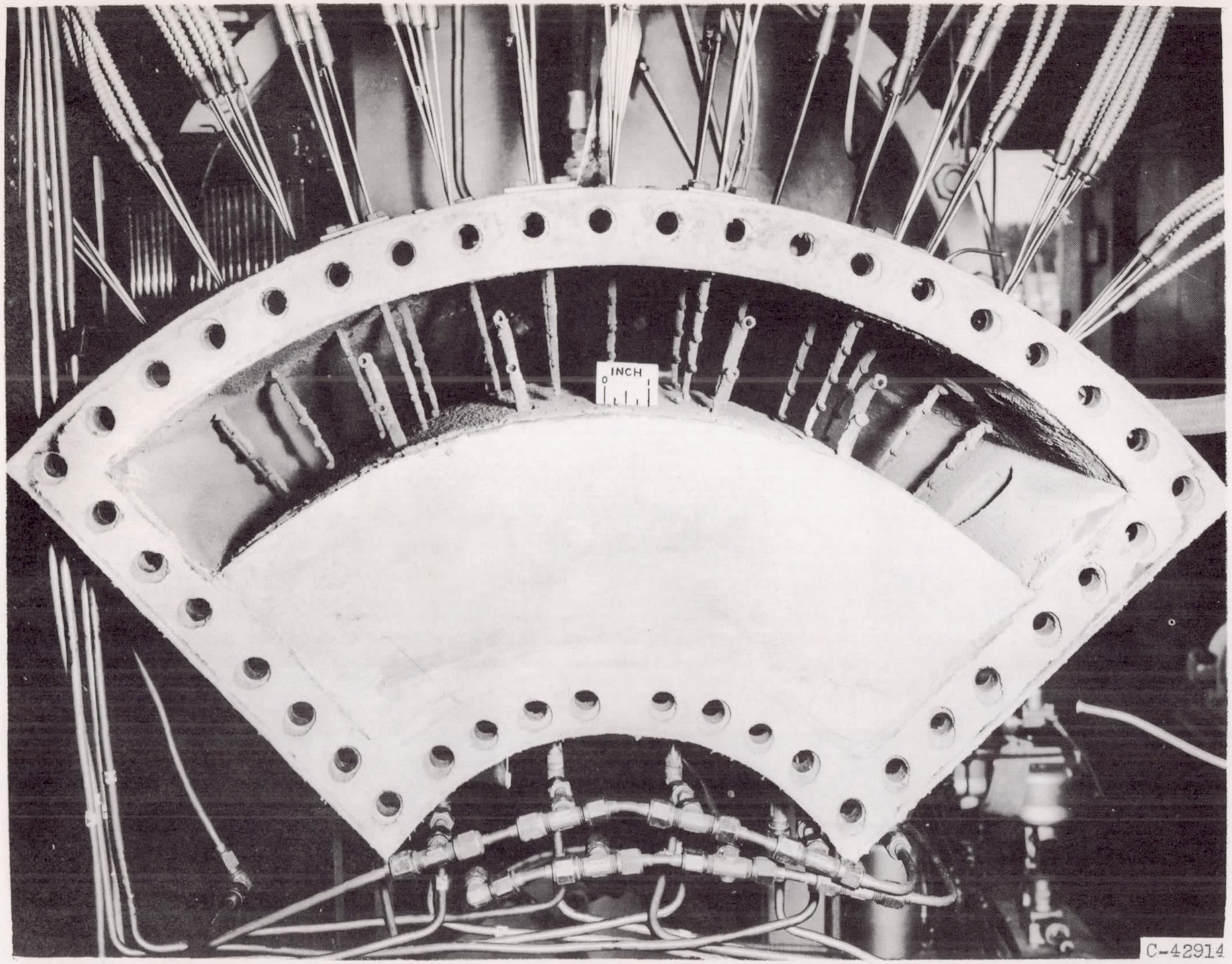

(c) Instrument section downstream of combustor.

Figure 8. - Concluded. Photographs of combustor after combustion of 15.6 pounds of Hi-Cal-3 fuel.

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