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U.S. NAVY
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14 March 1957

Report No. 1238

(Semiannual)

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UNDERWATER
PROPULSION
DEVICES

FC

Contract Nonr-1862(00)



Underwater Engine Division

Aerojet-General CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY
AZUSA, CALIFORNIA



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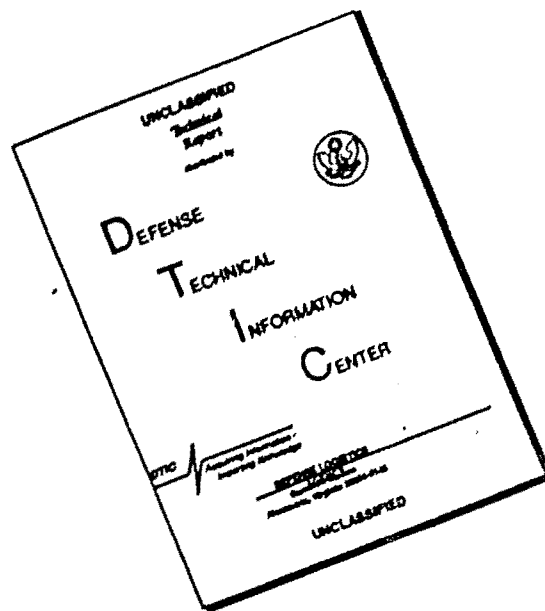
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14 March 1957

Report No. 1238
(Semiannual)

GENERAL RESEARCH IN THE
FIELD OF UNDERWATER PROPULSION DEVICES
AND ASSOCIATED EQUIPMENT

Contract Nonr 1863(00)

Written by:

L. B. Kelly
R. M. Viney

No. of Pages: 54

Approved by:

Period Covered:

6 June 1956 through 5 December 1956

C. A. Gongwer
C. A. Gongwer, Manager
Underwater Engine Division

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CONTRACT FULFILLMENT STATEMENT

This semiannual report is submitted in partial fulfillment of Contract Nonr 1863(00) and covers the period from 6 June 1956 through 5 December 1956.

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I. OBJECTIVE

The purpose of this program is to conduct general research in the field of underwater propulsion devices and associated equipment. During the period covered by this report, work was performed on several different types of underwater propulsion devices.

A. The first phase of the program was a theoretical investigation of the power-plant parameters for a small high-speed submarine. This feasibility study program was made to determine the general configuration, including sizes and weights, of the major components of an approximately 2000-shp submarine power plant using 90% concentrated hydrogen peroxide, diesel fuel, and sea-water diluent. The application of an exhaust-condensing system to this power plant was also to be studied and investigated.

B. The second phase of the program was an investigation of sea water used as a diluent in small engine systems using concentrated hydrogen peroxide and fuel oil. A literature survey of work accomplished by other agencies was to be conducted. New methods for the use of sea-water diluent were to be devised, investigated, and tested.

C. The third phase of the program was concerned with establishing the design of the free-running Alc0 hydroductor by suitable static and dynamic tests so that the depth insensitivity of the hydroductor can be proved.

II. SUMMARY

A. SUBMARINE POWER PLANT, FEASIBILITY STUDY

Results of this study program show that it is feasible to use a small chemical power plant for the small high-speed submarine. This power plant can use diesel fuel and 90% concentrated hydrogen peroxide as the propellant with sea-water diluent. All the major components for the 2000-shp power plant can be housed in a space 3 ft in diameter by 5 ft long. Initial calculations were made for non-condensing operation of this power plant system, and the study is continuing to include an exhaust-condensing system.

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II Summary (cont.)

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B. SEA-WATER-DILUENT PROGRAM

The use of sea water instead of fresh water as the diluent for hydrogen-peroxide engines would potentially improve the performance of these engines in torpedoes and other underwater vehicles. This program was planned to supplement previous efforts and to investigate other techniques for using sea water as a satisfactory diluent. In the sea-water-diluent program, several approaches to the problem have been investigated, either singly or in combination. Among them are the following:

1. Cationic-exchange treatment of the sea water
2. Additives to the sea water or fuel to change the nature of the solids formed, so that deposits will not occur or can be readily flushed away
3. Graphitic or other suitable coatings of the inside surfaces of the combustion hardware downstream of the sea-water injection zone, to discourage the adherence of solid deposits.

Tests were conducted using 70% E hydrogen peroxide and 92.5% ethyl alcohol, as well as 90% concentrated hydrogen peroxide and diesel fuel. Both synthetic and natural sea water were used as the diluent.

C. HYDRODUCTOR

Development effort has been continued on the hydroductor to prove its depth-insensitive performance characteristics. Primary effort has been placed on the development of the external-condensing hydroductor configuration because it promises to provide a more rapid solution to the design of the free-running hydroductor test vehicle. The initial testing was concerned with the determination of the most satisfactory afterbody shape for the external-condensing hydroductor.

III. CONCLUSIONS AND RECOMMENDATIONS

A. Partial results of the study program on the power plant for a small submarine show that it is feasible to design and develop a power plant capable

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III Conclusions and Recommendations, A (cont.)

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of meeting the preliminary specifications and utilizing 90% concentrated hydrogen peroxide, diesel fuel, and sea-water diluent. Overall performance of the power plant with a condensing system will be better than that of a plant without a condenser. In order to meet the requirements for various power levels and depths of operation, the condensing system would employ a condenser unit on the turbine itself, a pump for the condensing water, and a "froth" compressor-pump for the mixture of water and carbon dioxide between the condenser and the ambient sea water. It is recommended that this study program be completed and a special report published outlining the details of the investigation.

B. Preliminary data from the sea-water-diluent program indicated that most satisfactory operation will probably be obtained using a cationic-exchange treatment of the sea water with a suitable coating, such as graphite, applied to the internal surfaces of the combustion hardware. Preliminary tests with sea water containing additives, made in an attempt to change the nature of the solid deposits, were not satisfactory. The additives increased the total amount of solids passing through the system so that, while the nature of the deposits was changed, the amount of deposits was increased. It was also determined that only natural sea water, uncontaminated by fresh water or colloidal clay, should be used, because very different results were obtained when synthetic or harbor sea water was used. It is recommended that this program be continued with the primary emphasis placed upon cationic-exchange treatment of the sea water and that further investigation be made of the effects of combustion temperature on sea water used as a diluent.

C. The external-condensing configuration for the hydroductor promises to be a more satisfactory design for this unit. Conclusive data has not yet been obtained on the best afterbody shape. It is recommended that the necessary drag tests and tests with steam of the 3.25-in.-dia hydroductor model be made on the rotating boom in order to prove performance potential.

IV. SUBMARINE POWER PLANT, FEASIBILITY STUDY PROGRAM

A. The potential use of small high-speed submarines has made it desirable to conduct a feasibility study program on a power-plant system that would be

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IV Submarine Power Plant, Feasibility
Study Program, A (cont.)

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applicable. Since the space available for the power plant is extremely limited, a chemical system is probably the most desirable. A great deal of development work has been conducted on hydrogen-peroxide systems and very promising results have been obtained. For this reason, a power plant utilizing 90% concentrated hydrogen peroxide, diesel fuel, and sea-water diluent was chosen for this investigation. In the light of other information, obtained from a study program at the Aerojet-General Corporation regarding the possible size and shape of a small high-speed submarine, an arbitrary space allotment of 3 ft OD by 5 ft long was made for the power-plant system. Within this space it was desired to house all the major components of a minimum-weight power-plant system suitable for producing approximately 2000 shp. The investigation was to include the following power-plant components:

1. Flexible propellant tanks, exposed externally to the ambient sea water
2. Hot-zone combustion chamber, with diluent sea water injected downstream
3. Impulse turbine, operated at 1900°F
4. Propellant pumps, geared to the turbine shaft
5. Quiet reduction gear train, with a 2100-rpm counter-rotating output
6. Jet condenser-ejector system on the turbine exhaust, if possible.

The power plant should be capable of operation for a 2-hr duty cycle without changing the catalyst cartridge in the decomposition chamber. Power output should be variable up to 2000 shp, at operating depths from the surface to 1000 ft. It should be possible to transport and use the power plant in an upside-down position. The propeller thrusts should be reversible. All power-plant components should be located external to the personnel pressure-hull. Total expendables carried are limited to 5 tons by the hull space available for storage of propellants.

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IV Submarine Power Plant, Feasibility Study Program (cont.)

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B. A literature survey was made of the existing and proposed submarine and torpedo power plants which utilize concentrated hydrogen peroxide and diesel fuel with water as a diluent. This survey included a review of the work on the Alton closed-cycle engine, the Walter-cycle engine, and the development program of the Mk 42 torpedo. With this background information, the possibilities of using a jet condenser-ejector system to reduce the turbine back pressure of the steam and CO_2 exhaust products, during operation at the greater depths, were explored. It was decided that serious consideration could not be given to such a system since it could not be made flexible enough for efficient operation from the surface to 1000-ft depths and at various turbine-power and speed settings throughout this range of depths. The problems of utilizing ambient sea water for a diluent are being investigated (see Section V) and their relation to the proposed submarine power-plant system is being studied.

C. On the basis of the performance calculations and the studies conducted during this report period, the following general characteristics and features of the power-plant system have been determined:

1. Double-wall bags of synthetic resin (Mylar inside, for chemical inertness; Dacron outside, for strength) were chosen to hold the peroxide, fuel, and fresh water for turbine cooling. Special gravity shutoff and vent valves will be provided to vent the peroxide in both the upside-down and erect positions.

2. Operating temperature of the turbine will be above the melting temperature of the untreated sea-water salts (1850°F). The turbine wheel will be cooled with two small fresh-water sprays to permit full-duty-cycle operation. A sea-water spray will be introduced into the turbine exhaust system to wash out possible salt deposits. The diameter of the turbine will be approximately 12 in. and its speed will be approximately 25,000 rpm.

3. Special sliding-ring, variable-displacement, positive-displacement vane pumps will be used for all propellants, exhaust-flushing sea water, turbine-cooling water, and lubricating oil. To assure constant ratios of flow through all six pumps, regardless of the power setting, these pumps are to be

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IV Submarine Power Plant, Feasibility
Study Program, C (cont.)

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geared to the turbine. Power-plant control and variation of settings for power and speed will be accomplished by means of a simple, manually operated system of cams which control the displacements of all six pumps in equal proportions. A low-power, battery-driven motor will be used for starting. This operation will be performed while the pumps are disconnected from the main power plant. The pumps are brought to operating level by a special clutch which engages when the turbine reaches a certain speed.

4. From studies conducted on the possibilities of providing for thrust-reversing (variable-pitch) propellers, it was concluded that such a design for reversing the submarine would involve more time than the scope of this power-plant program will allow. Alternative systems were therefore considered. For example, provision for reversing the submarine could be accomplished by the use of a small 30-hp Terry-type turbine directly connected to the drive shaft of the main 2000-shp turbine. This reversing turbine could be powered by decomposed 90% concentrated hydrogen peroxide and could be controlled by a special bypass valve on the discharge of the main H_2O_2 vane pump. The best possibility for reversing appears to be the use of a 5-hp d-c motor, connected to the main turbine shaft through a clutch. This motor could also be used for starting and low-speed cruising.

5. Thermodynamic calculations were completed for the combustion and reaction processes of a bluff-body type of gas generator using 90% hydrogen peroxide, diesel fuel, and sea-water diluent. For a thermal equilibrium temperature of $1900^{\circ}F$ at the turbine nozzle inlets, the following propellant mixture ratios were calculated: 8 parts by weight of 90% concentrated hydrogen peroxide, 1 part diesel fuel, and 7.7 parts sea-water diluent. The temperature of the primary (hot) combustion zone would be $4950^{\circ}F$. Calculated values for C_p/C_v (γ) and characteristic velocity (C^*) of the reaction products at nozzle inlet conditions were 1.223 and 3630 ft/sec, respectively. The bluff-body type of combustion chamber being considered is similar to the combustion chamber developed for the Bureau of Ordnance under Contract NOrd 16510, as shown in Figures 1, 2, and 3. This type of combustion chamber is very reliable, efficient, and flexible

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IV Submarine Power Plant, Feasibility
Study Program, C (cont.)

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for peroxide fuel and sea-water systems and will operate successfully with a large percentage of undecomposed hydrogen peroxide entering the primary "hot" combustion zone.

6. The study was completed of a single-stage, impulse-type turbine configuration which would give optimum performance, permitting submarine cruising speeds as low as 10 knots at a 1000-ft depth without the use of an exhaust-condensing system. This configuration has the following characteristics:

- a. Twenty-nine nozzles, full-admission, 1.26-in.² total nozzle-throat area
- b. Turbine speed, 25,000 rpm
- c. Turbine wheel, pitch diameter of 12 in. and maximum peripheral speed of 1300 ft/sec
- d. Three separate decomposition and combustion-chamber systems (A, B, and C), each connected to an individual bank of nozzles.

System A has a maximum P_c of 2300 psia and is connected to three nozzle ports. System B has a maximum P_c of 2300 psia and is connected to 14 nozzle ports. System C, with a maximum P_c of 1025 psia, is connected to 12 nozzle ports. Systems A and B are used together for the larger power requirements at 300 to 1000-ft depths. System A is used alone for low-speed operation (as low as 10 knots) at 300 to 1000-ft depths. All systems and nozzles are used together for operation from the surface to a depth of 300 ft.

7. From the investigations of the main high-speed reduction-gear train, it appears that a planetary spur-gear system provides the smallest and lightest-weight configuration. From the standpoint of size and simplicity, the best location for the main thrust bearings was determined to be next to the main gear housing. The investigation of optimum gear-train configurations included drives and special overspeed cutoffs for the auxiliaries.

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IV Submarine Power Plant, Feasibility
Study Program (cont.)

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D. The results of these studies were reviewed with one of Aerojet's consultants, an expert in the field of H_2O_2 submarines, and the following recommendations were made:

1. Studies should be conducted on feasible power plants employing a condensing system for the turbine exhaust products. This condensing system would employ a condenser unit on the turbine exhaust, a pump for the condensing water, and a "froth" compressor-pump (for the mixture of water and carbon dioxide) between the condenser and ambient sea water.

2. Design of an air-breathing engine for auxiliary power, entirely independent of the main power plant and possibly located within the personnel compartment, should be investigated.

3. Calculations were made for the most suitable condensing-zone pressure, taking into consideration the turbine performance vs the size and weight of the condensing-system components. A condensing-zone pressure of 60 psia was selected. Turbine-performance calculations were as follows:

Chamber pressure, $P_c = 580$ psia at surface

$= 648$ psia at 1000-ft depth

Chamber temperature, $T_c = 1900^\circ F$

Peripheral velocity, $\mu = 1310$ ft/sec

Turbine power = 2102 shp at surface

$= 2350$ shp at 1000-ft depth

Characteristic velocity, $C^* = 3690$ ft/sec

Nozzle expansion ratio, $e = 2.5$

Nozzle throat area, $A_t = 1.26$ in.²

Specific heat ratio, $\gamma = 1.223$

Nozzle angle, $\beta = 16^\circ$ actual

$= 19^\circ$ effective

Efficiency, $\eta = 56.8\%$

Specific expendables consumption (turbine), $SFC_{exp} = 5.85$ lb/shp-hr
at surface

$= 5.85$ lb/shp-hr
at 1000-ft
depth

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IV Submarine Power Plant, Feasibility Study Program, D (cont.)

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4. The five primary advantages gained from a power plant which incorporates a condensing system for turbine exhaust products are as follows:

- a. An improved turbine performance is possible at depth.
- b. Only single decomposition- and combustion-chamber assemblies are required.
- c. A much lower combustion pressure occurs at depth, requiring less power for the propellant pumps and also permitting lighter combustion hardware.
- d. The flushing conditions for the sea-water solids in the turbine-exhaust system are greatly improved.
- e. A shorter length is required for the entire power plant.

5. The disadvantages of a condensing system are found in the slight increase in weight and complexity of the complete power plant. The direct-condenser unit, the condensing-water pump, and the "froth" pump-compressor are now being investigated.

6. This study program will be completed by approximately 15 February 1957. It is planned that a special report will be published to include performance calculations, schematic diagrams of the power-plant system, and the necessary layout drawings of the major components, in order to confirm the general size and weight of the complete power-plant system.

V. SEA-WATER-DILUENT PROGRAM

A. PURPOSE

One of the best chemical power-plant systems at present uses hydrogen peroxide and a hydrocarbon fuel. Such a plant is relatively efficient and essentially wakeless. The latter characteristic is of primary importance as regards use in torpedoes and submarines. However, because the reaction temperatures of hydrogen peroxide and a hydrocarbon fuel are excessive for turbine operation, diluent water must be added to cool the gases to a reasonable

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V Sea-Water-Diluent Program, A (cont.)

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temperature, in order to prevent erosion or overstressing of the turbine blades. Fresh water is normally carried by the vehicle for this purpose, but the considerable space occupied by fresh-water tanks could be available for additional propellant if ambient sea water were used as the diluent. The use of sea water as a diluent for hydrogen-peroxide engines has been investigated by several agencies, but completely satisfactory performance has not been obtained.

B. PROGRAM PLAN

This program was planned to supplement previous efforts and to investigate other techniques for obtaining satisfactory use of sea water as a diluent. First, a literature survey was conducted. This included work accomplished by and for the U.S. Navy and also the work conducted in Germany on the use of sea-water diluent. One of the best sources of information was Reference 1. Other sources were reports from USNOTS, Pasadena, California; the Food Machinery and Chemical Corporation, Becco Chemical Division, Buffalo, New York; and Professor Helmut Walter, Worthington Pump and Machinery Corporation, Harrison, New Jersey. With this background information as a guide, the diluent problem is being investigated in several ways, which include the following approaches, either singly or in combination:

1. Cationic-exchange treatment of the sea water
2. Additives to the sea water or fuel to change the nature of the solids formed, so that deposits will not occur or can be readily flushed away
3. Graphitic or other suitable coatings on the inside surfaces of the combustion hardware downstream of the sea-water injection zone, to lessen the adherence of solid deposits.

C. METHOD OF TEST

1. A thrust-dynamometer installation was prepared in order to simulate solid-deposit conditions on turbine blades and in a turbine-exhaust system with a gas generator utilizing hydrogen peroxide and fuel. A Mk 16-6 torpedo energy section and a new combustion chamber of an experimental design (see Figures 1, 2, and 3), developed under Contract NOrd 16510, were used for

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V Sea-Water-Diluent Program, C (cont.)

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all the tests conducted with 70% E hydrogen peroxide and 92.5% ethyl alcohol. For the tests made with 90% concentrated hydrogen peroxide and diesel fuel, this combustion chamber was slightly modified by changing the construction of the bluff-body fuel injector and flameholder. Although the main objective of the program is to determine the best method for utilizing ambient sea water with a combustion system employing 90% concentrated hydrogen peroxide and diesel fuel, it was realized that very pertinent and important information concerning the use of sea-water ion exchange and additive techniques could be obtained by using lower-strength peroxide and alcohol as energy sources at the start of the test series. Furthermore, test equipment was on hand (through the cooperation of the Bureau of Ordnance) and its use resulted in a saving of much time and money for this program.

2. A special adapter containing a steel bar and two steel collector screens was placed downstream of the gas-generator nozzle to simulate the turbine blades and turbine-exhaust system. Following each test run, the deposits of sea-water salts in the combustion chamber and collector system were photographed, weighed, and chemically analyzed. A photograph of the complete thrust-dynamometer-test installation is presented in Figure 4. The three propellant flowmeters (orifice-d/p cell type) are shown on the side of the thrust stand. (The Annin valves on the meter lines are not used for this program; flows are controlled with Waterman-type constant-delivery valves.) The stainless-steel sea-water-diluent tank is visible at the left side of the photograph against the wall of the test pit. The Mk 16-6 torpedo peroxide and fuel tanks are located inside the steel box at the right.

D. RESULTS OF TESTS

1. The first series of tests was conducted using a synthetic sea-water diluent, made by adding distilled water to a typical sea-water salt formation (obtained from Mefford Chemical Company). It was desired to compare the results from these tests with results of tests using natural sea water, and a quantity of sea water was obtained from the harbor at Seal Beach, California. The results of these tests were not as expected and it was concluded that the

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V Sea-Water-Diluent Program, D (cont.)

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harbor sea water contained small amounts of fresh water and colloidal clay. Subsequently, a quantity of sea water was obtained two miles offshore from Seal Beach and this was used in the later tests during the report period. The analyses of the composition of the synthetic sea-water sample and the harbor sea-water sample are presented in Table 1. The offshore sea-water sample is being analyzed and results will be reported at a later date.

2. A brief description of all tests conducted is shown in Table 2. The data regarding the total weight of solids introduced into the system during the test run and the weight of solids deposited in the combustion chamber and exhaust system are presented in Table 3. The following information was obtained from this series of tests:

a. Runs No. 1, 8, and 13 were made in order to compare the type of solid deposits obtained when using synthetic sea water, the harbor sample of sea water, and the offshore sample of sea water. The presence of slight amounts of fresh water and colloidal clay in the harbor sea water evidently had an influence on the solid deposits in that they were soft and appeared as if they would wash away readily. The smallest amount of solid deposits was found when the offshore sea water was used. (See Figures 5, 6, 7, 8, 9, 10, and 11.)

b. The cationic-exchange treatment of the sea water had a material effect on the amount of solids deposited in the system (see Figure 12). Further investigation of this method, using natural sea water, is planned.

c. It was hoped that the addition of suitable additives to the sea-water diluent would change the type of salt deposits so that they would not adhere to inside hardware surfaces, or that they would be of such a nature as to be readily flushed away. This hypothesis was not borne out; actually, the use of additives increased the total amount of solids passing through the system and increased the total amount of solid deposits (see Figures 13, 14, and 15).

d. The coating of graphite and varnish applied to the internal surfaces of the combustion chamber in the exhaust system in Run No. 6 materially decreased the amount of solids deposited (see Figure 16). This type of coating will be tested again, using natural sea water.

e. The preliminary data obtained during these tests on the effect of low combustion-chamber temperature indicated that the amount of solids deposited downstream of the nozzle was increased (see Figure 17). Additional tests are planned to study this phase during the coming period. Other tests will also be made to determine the differences between operation of a combustion chamber using 70% E hydrogen peroxide, ethyl alcohol, and sea-water diluent, and one using 90% hydrogen peroxide, diesel fuel, and sea-water diluent.

VI. HYDRODUCTOR

A. HISTORY OF DEVELOPMENT

1. An underwater missile such as the Alc0 hydroduct is propelled by a jet of high-velocity steam exhausting through a De Laval nozzle. However, as the missile achieves greater depth and the back pressure increases, the steam velocity decreases and the thrust of the system deteriorates until the power plant becomes inoperative. This phenomenon imposes a limitation on the missile and restricts its maximum service depth to a value governed by the pressure in the combustion chamber. By condensing the exhaust with a steam-jet condenser, a low back pressure on the steam nozzle can be maintained, and the performance of the missile can be increased and made relatively insensitive to depth. Since the exhaust of the Alc0 hydroduct consists of steam and solid reaction products, and is therefore completely condensable, a direct-contact condenser can be applied to the system. When a steam-jet condenser is applied to the hydroduct, the device is termed a hydroductor. A schematic diagram of the hydroductor is shown in Figure 18.

2. The steam-jet condenser design is such that sufficient quantities of sea water to condense the exhaust steam are ducted into the chamber through external scoops. The design of the sea-water inlet orifices in the scoop is such that the total pressure head, equal to the sum of ram- and static-pressure heads, is totally converted to velocity head. The pressure within the mixing chamber is the vapor pressure of the condensed mixture and amounts to only a few pounds per square inch absolute. This condition produces an extremely high steam-exhaust

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VI Hydroductor, A (cont.)

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velocity, by permitting expansion from the initial conditions down to a very low enthalpy level. Through impact, and by an exchange of momentum between the steam and water particles, the mixture achieves a high velocity at the end of the condensing chamber. After leaving the condensing chamber, the high-velocity mixture passes through a diffuser, where a portion of the velocity is converted into a pressure head matching the ambient conditions of the particular depth where the vehicle is operating. The reaction products at operating temperatures will be solids, and the steam will be totally condensed within the mixing chamber, thereby giving a vehicle with no gaseous wake. The previous work on the development of the hydroductor, conducted on Contract N6ori-10, Task Order 1, with the Office of Naval Research, is reviewed in Reference 2.

3. Several free-running tests were made of the 4.5-in.-dia Alcide hydroductor test missile (see Figure 19) under sponsorship of the Armament Branch, Office of Naval Research, Contract Nour 1002(00). Performance of the free-running test missile was not judged to be completely successful because there was, apparently, excessive drag of the test-missile configuration. Results of these tests have been reported in References 3, 4, 5, and 6.

B. PURPOSE OF PRESENT PROGRAM

The operational advantages to be gained from an underwater missile capable of high velocities, and whose performance is relatively insensitive to depth, were realized to be important enough to justify continued development effort on the hydroductor. The fact that the free-running hydroductor test vehicle did not establish an equilibrium running velocity indicated that there was either excessive drag of the test vehicle configuration or that sufficient water was not being forced into the condensing section for proper operation of the motor, or that both of these conditions prevailed. The problem was to be approached in the following ways:

1. It was possible that the excessive drag of the internal-condensing hydroductor configuration (Figures 18 and 19) occurred because properly vented flow was not established through the condensing-water scoops. This would result in insufficient water for the condensing section of the motor and would

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VI Hydroductor, B (cont.)

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consequently reduce the thrust. Moreover, and probably of a more serious nature, separation of the external flow at the lip of the condensing-water scoop would occur, and this would materially increase the drag of the test vehicle. It was therefore planned to study the flow conditions associated with a condenser of this kind by constructing a two-dimensional model of this configuration. A section of the steam nozzle and condensing-water scoop would be modeled and placed between Plexiglas walls so that the flow conditions could be readily studied. The high-pressure pumping equipment and steam from the Aerojet stationary power plant were available for this purpose (see Reference 7).

2. A second approach to this problem was to be made by studying and testing an external-condensing hydroductor configuration. The immediate problem of excessive drag associated with the condensing-water scoop would be avoided by using this type of unit. From the results of some of the studies on the condensing of steam jets, conducted under Contract Nonr 869(00), it was determined that this type of hydroductor configuration might be feasible. A measure of depth-insensitivity could be expected without a serious increase in total drag of the missile through proper design of the steam nozzles and afterbody of the missile. Under shallow-water operating conditions, the motor would run as a hydroduct. When the ambient back pressure increased due to greater operating depth, the steam cavity would be made shorter because of the increased pressure. The flow pattern would change under these conditions, so that some of this pressure could be recovered on the afterbody of the missile; reduced drag would result. The study and testing of the external-condensing hydroductor configuration was emphasized during this report period because such work promised to provide a more rapid solution to the design of the free-running hydroductor test vehicle.

C. TEST PROGRAM

1. The first step in the testing program on the external-condensing hydroductor was to determine the most favorable configuration of the steam nozzle and afterbody section. Tests were planned to determine whether there is significantly less drag of any particular model and whether it is possible to force the

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VI Hydroductor, C (cont.)

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water from a cup-shaped afterbody into a partial re-entrant jet without assistance from the steam nozzles. In addition to a completely faired body (for reference purposes), the tail-section shapes shown in Figure 20 were chosen for initial testing. The ghost lines shown in the drawing of one of these tail sections (Figure 21) represent one of the proposed interior configurations of the tail section of the external-condensing hydroductor. Instead of one central steam nozzle, there will be an annular ring of small nozzles so located that they discharge almost parallel to the steam flow around the tail section.

2. The basic model used for the drag tests was the 3.25-in.-dia test model (Figure 22) used in several previous programs. This model is attached to a hollow strut through which steam can be delivered to the model. For the drag tests, the tail section of the model was replaced by sections of the experimental shapes, without any steam nozzles. The special test-model tail sections were cylindrical and so designed that the total skin area, exclusive of the base area, was the same as that of the completely faired tail section. The model and strut were mounted on the extension arm of the rotating boom at the 50-ft radius. Drag measurements were obtained at velocities up to 158 ft/sec. Two complete sets of drag measurements were obtained for each model tested. Tests were completed on the faired afterbody, Model A, and Model C, and the drag curves obtained are shown in Figure 23. The drag values shown are the gross values obtained, which include the drag of the model and the strut, since it was desired to determine the differences in the drag values of the various afterbody shapes. Figure 23 shows the difference between the drag of a square-ended model and a model with a concave cup shape, compared with that of the faired afterbody. Tests are planned for the other shapes shown in Figure 20, in order to complete the studies of the influence of the shape of the afterbody on the drag of the test vehicle.

3. Models are being designed so that further performance tests of the external-condensing hydroductor can be made with steam on the rotating boom. The nozzle block for these models will have 20 small nozzles in an annular ring. The combined throat area of these nozzles will be the same as that of the hydroduct model shown in Figure 22, so that comparative performance tests can be made.

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1. J. F. Brady, The Use of Sea Water as a Diluent in Torpedo Combustion Systems, U.S. Naval Underwater Ordnance Station, Newport, R.I., 25 May 1954.
2. Research, Development, and Testing of Underwater Propulsion Devices, Aerojet Report No. 1106, 31 May 1956 (Confidential).
3. Range Testing of the 4.5-in. Alclo Hydroduct, Aerojet Report No. L2815-9, 14 January 1954 (Confidential).
4. Range Testing of the 4.5-in. Alclo Hydroduct, Aerojet Report No. L2815-27, 7 July 1955 (Secret).
5. Range Testing of the 4.5-in. Alclo Hydroduct, Aerojet Report No. L2815-35, 20 March 1956 (Confidential).
6. Range Testing of the 4.5-in. Alclo Hydroduct, Aerojet Report No. L2815-36, 2 April 1956 (Confidential).
7. Steam-Jet Condenser for Hydroductor Propulsion System, Aerojet Report No. 707, 25 May 1953 (Confidential).

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TABLE 1

COMPOSITION OF SEA-WATER-DILUENT SAMPLES

<u>Element</u>	<u>Synthetic Sea Water (Diluent "E") % by wt</u>	<u>Harbor Sea Water (Diluent "F") % by wt</u>
Sodium	27.0	25.0
Magnesium	4.1	4.9
Calcium	3.8	4.2
Aluminum	0.0028	0.0038
Silicon	0.039	0.063
Potassium	3.2	3.1
Strontium	0.11	0.063
Chromium	trace	0.00047
Iron	0.033	0.016
Boron	0.080	0.072
Copper	0.0024	0.00048

Table 1

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TABLE 2

DESCRIPTION OF TESTS, ONR SEA-WATER-DILUENT PROGRAMS

Run No.	Fuel ¹ and Flow Rate lb/min	Oxidizer ² and Flow Rate lb/min	Diluent ³ and Flow Rate lb/min	Diluent Additive	Average Combustion Temperature °F	Decationized Amount of Diluent %	Remarks
1	A - 8.05	C - 46.0	E - 25.0	None	--	None	Reference run. Considerable deposit of salts in chamber and on collectors. Run duration 3 min. ⁴
2	A - 10.4	C - 42.5	E - 25.1	None	1340	36.8	Sea water acidic from ion exchange process. Salt deposits 20% of Run No. 1.
3	A - 10.3	C - 44.8	E - 24.4	None	1580	50.0	Results similar to Run No. 2.
4	A - 9.9	C - 44.7	E - 22.2	HCl	1578	None	Considerable deposits of salts in chamber and on collectors. Less than Run No. 1, however.
5	A - 10.9	C - 43.7	E - 18.9	ZnCl ₂	1670	None	Additive increased amount of solids produced but did not satisfactorily decrease amount of solids deposited.
6	A - 9.9	C - 40.8	E - 18.3	None	1620	None	Graphite and varnish applied to internal surface of combustion chamber and exhaust system. Materially less deposits of salts than Run No. 1.
7	A - 10.1	C - 41.3	E - 21.5	FeCl ₃	--	None	Reaction products appeared to form oxides and considerable deposit of solids in system.
8	A - 9.8	C - 40.4	F - 23.6	None	--	None	Slightly more solid deposits than Run No. 1 but of a soft, putty-like composition.
9	A - 11.0	C - 41.4	F - 22.0	NaOH	1730	None	More solid deposit in exhaust system than Run No. 8, and of hard-crust composition.
10	B - 3.8	D - 32.8	F - 20.0	None	2340+	None	45-sec duration run. Collector system not used so that exhaust could be observed. Diluent flow rate lower than desired. Bluff-body flame holder and injector requires slight modification for this fuel and oxidizer.
11	A - 9.5	C - 42.7	E - 20.0	NaOH	1490	None	Results comparable to Run No. 9.
12	A - 9.7	C - 41.0	E - 18.9	KOH	1300	None	Results slightly better than Run No. 11.
13	A - 9.4	C - 39.0	G - 21.7	None	1550	None	Reference run. Solid deposits of similar appearance to Run No. 1 but of less magnitude than both Runs No. 1 and 8.
14	B - 2.9	D - 29.2	G - 22.4	None	2000	None	Fuel leak invalidated run for use as reference.
15	B - 4.2	D - 31.6	G - 21.9	None	2000+	None	Run cut short because of malfunction of diluent control valve.
16	A - 5.5	C - 29.7	G - 22.5	None	1100	None	Slightly less deposit of solids in combustion chamber and more deposit in exhaust system than Run No. 13.

NOTES: (1) Fuel "A" is 92.5% ethyl alcohol.
Fuel "B" is diesel oil.

(2) Oxidizer "C" is 70% concentrated hydrogen peroxide.
Oxidizer "D" is 90% concentrated hydrogen peroxide.

(3) Diluent "E" is synthetic sea water.
Diluent "F" is natural sea water obtained from the harbor at Seal Beach, California.
Diluent "G" is natural sea water obtained 2 miles offshore from Seal Beach, California.

(4) All runs were of 2 min duration unless otherwise noted.

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TABLE 3

TEST DATA, ONR SEA-WATER-DILUENT PROGRAM

Run No.	Description	Total Weight of Solids into System During 2-Min Running Time lb	Total Weight of Solids Deposited in 2-Min Running Time		Ratio of Sodium to Calcium in Exhaust System Deposits, (1) lb
			Combustion Chamber, lb	Exhaust System, (1) lb	
1	100% synthetic sea water (reference run)	1.62	0.254	0.127	13:1
2	36.8% decationized syn- thetic sea water and 63.2% untreated syn- thetic sea water	1.09	0.086	0.043	35:1
3	50% decationized syn- thetic sea water and 50% untreated synthetic sea water	0.84	0.069	0.051	12:1
4	Synthetic sea water with HCl added (2)	1.52	0.16	0.061	13:1
5	Synthetic sea water with ZnCl ₂ added (3)	5.24	0.35	0.036	4:1
6	100% synthetic sea water; interiors of system coated with graphite	1.33	0.15	0.038	5:1
7	Synthetic sea water with FeCl ₃ added (4)	5.83	0.25	0.15	6:1
8	100% natural sea water	1.62	0.27	0.19	15:1
9	Natural sea water with NaOH added (5)	5.06	0.17	0.40	240:1
11	Synthetic sea water with NaOH added (5)	4.48	0.15	0.32	17:1
12	Synthetic sea water with KOH added (6)	5.32	0.10	0.19	4:1
13	Offshore sea water	1.49	0.14	0.062	15:1

(See Sheet 2 for notes)

Table 3
Sheet 1 of 2

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TABLE 3 (cont.)

Run No.	Description	Total Weight of Solids into System During 2-Min Running Time	Total Weight of Solids Deposited in 2-Min Running Time		Ratio of Sodium to Calcium in Exhaust System Deposits ⁽¹⁾
		lb	Combustion Chamber, lb	Exhaust System ⁽¹⁾ lb	
14	Offshore sea water, 90% H ₂ O ₂ , and diesel fuel	1.542	0.092	0.026	17:1
16	Offshore sea water, 70% E H ₂ O ₂ , and ethyl alcohol	1.548	0.11	0.089	14:1

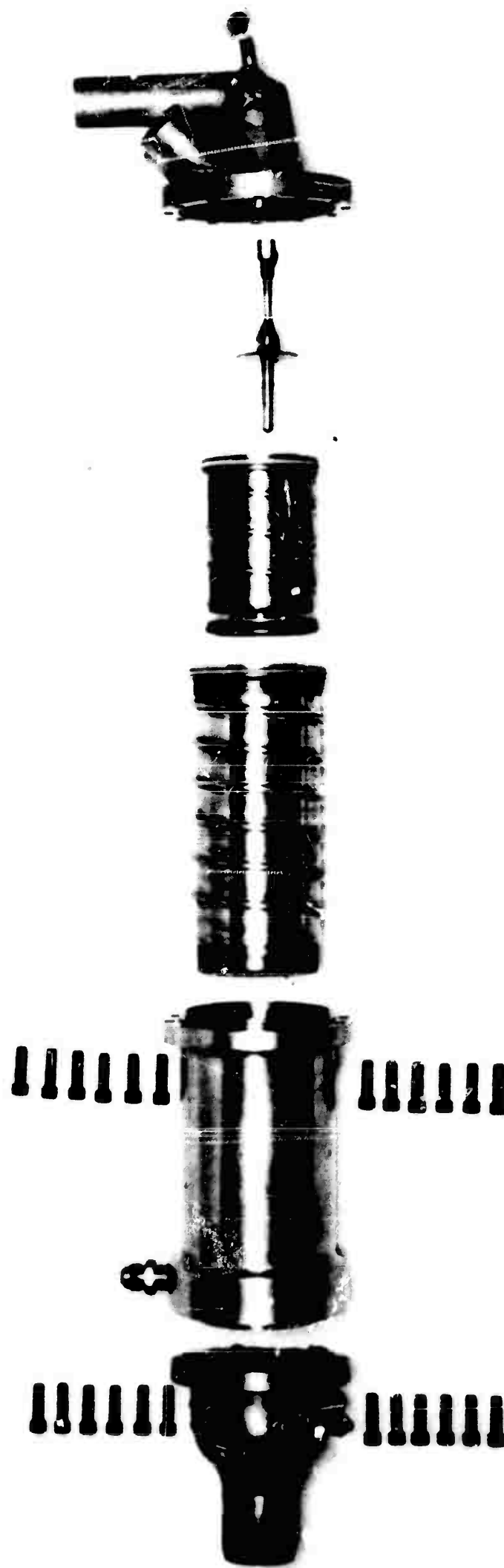
NOTES:

- (1) Water-soluble solids only.
- (2) HCl added in such an amount that the acid-to-solids ratio was equal to that produced by the partial ion exchange of Run No. 3.
- (3) ZnCl₂ added in such an amount as to produce a eutectic with the sea-water salts (taken as NaCl) having a melting temperature of 503°F - 58.5 mole% ZnCl₂.
- (4) FeCl₃ added in such an amount as to produce a eutectic with the sea-water salts (taken as NaCl) having a melting temperature of 316°F - 54 mole% FeCl₃.
- (5) NaOH added in such an amount as to produce a mixture with the sea-water salts (taken as NaCl) having a melting temperature of 680°F - 78 mole% NaOH.
- (6) KOH added in such an amount as to produce a mixture with the sea-water salts for which the melting temperature is undetermined - 78 mole% KOH.

Table 3
Sheet 2 of 2

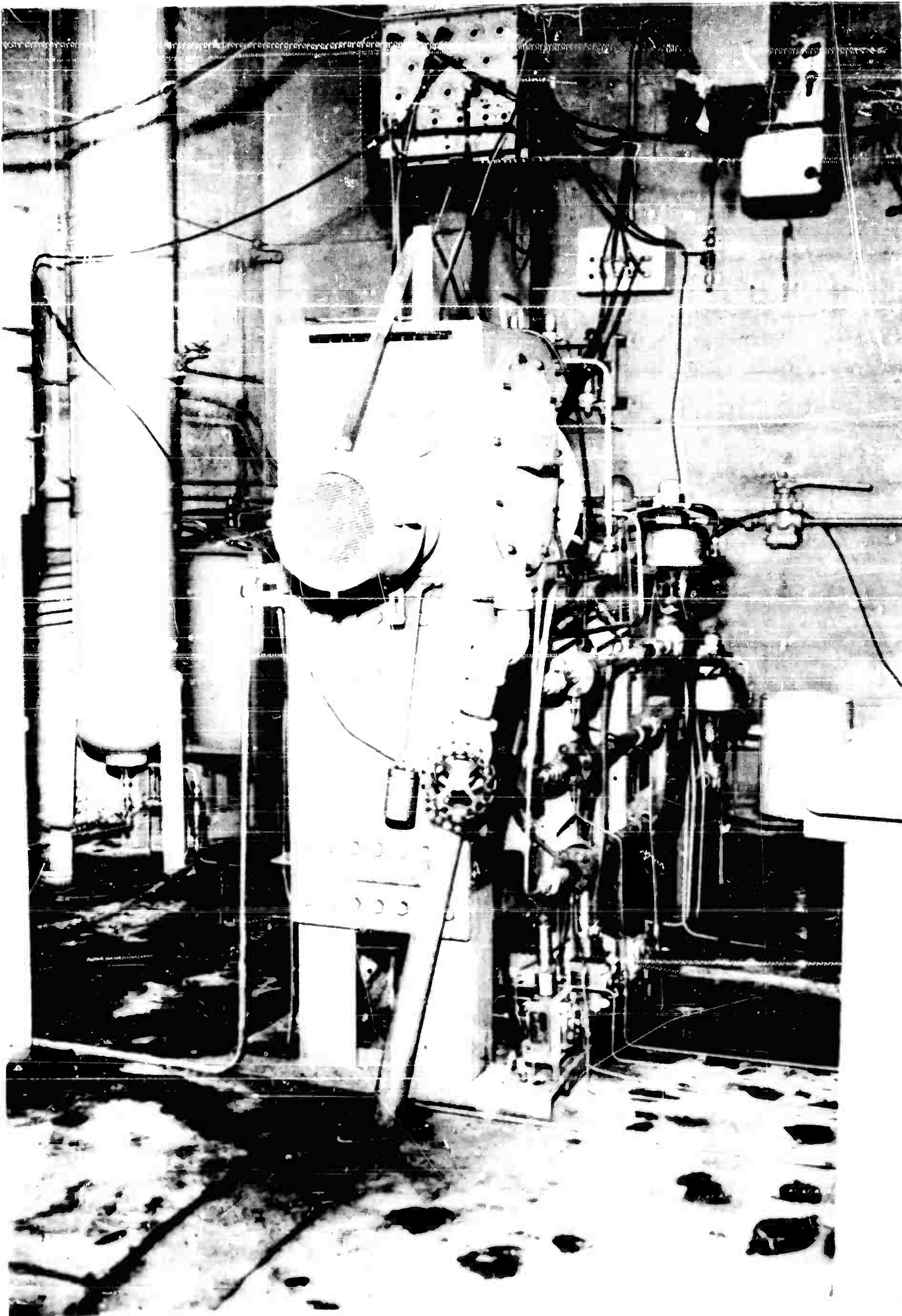
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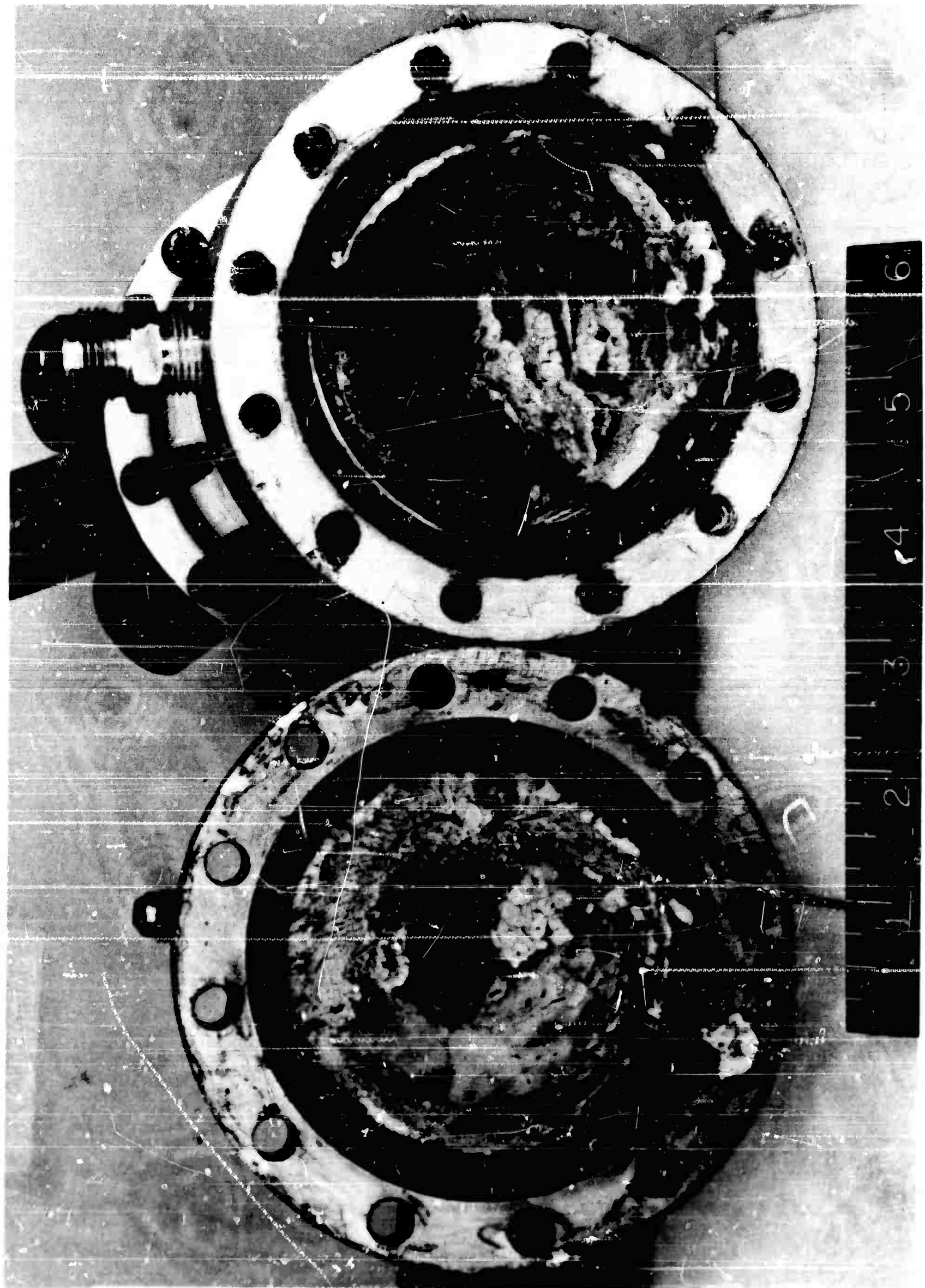
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Combustion Chamber of Experimental Design No. 1 Mod 1 for the MK 16-6 Torpedo - - Disassembled View



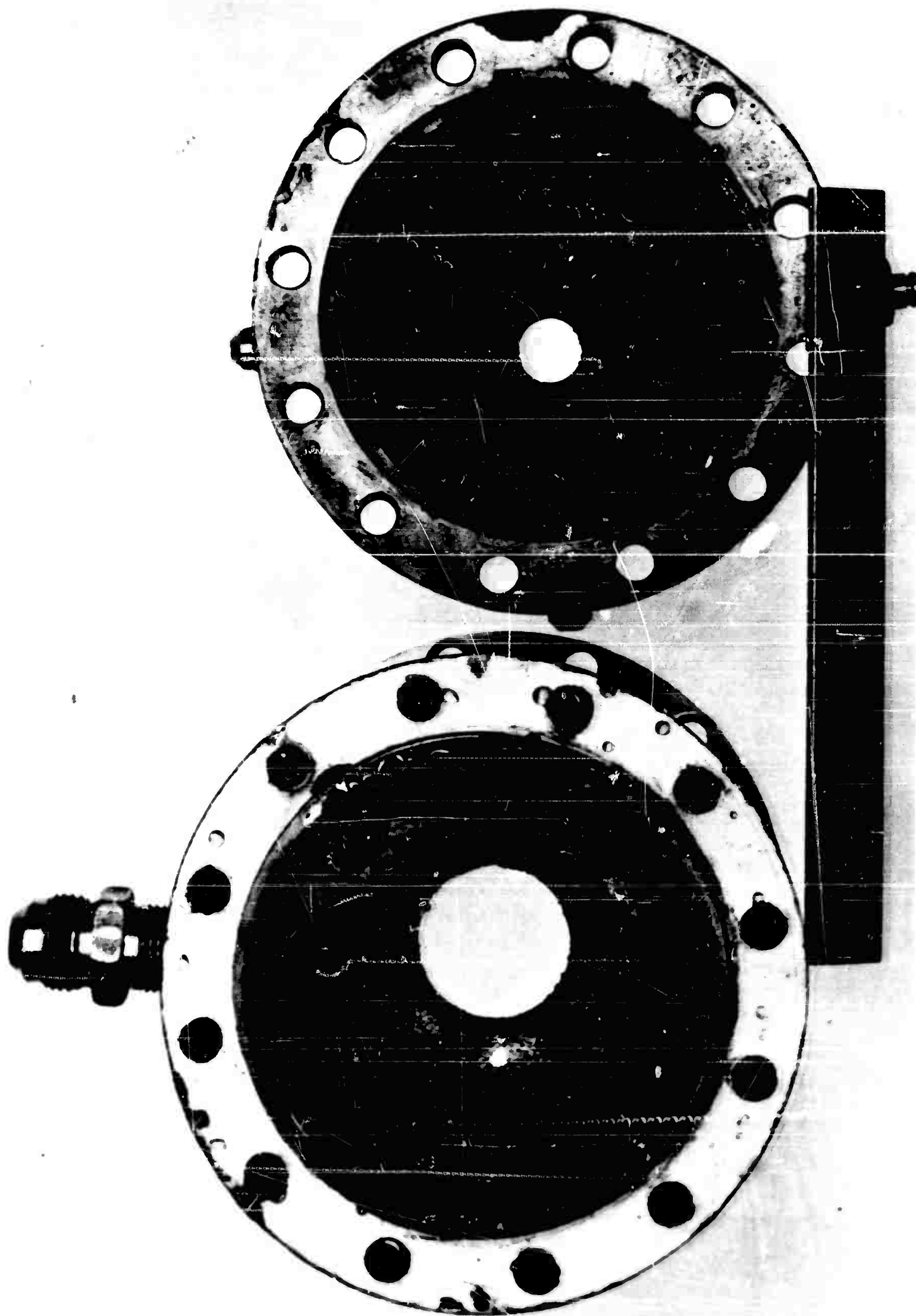
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Thrust-Dynamometer Installation for H_2O_2 Combustion-System
Sea-Water-Diluent Tests



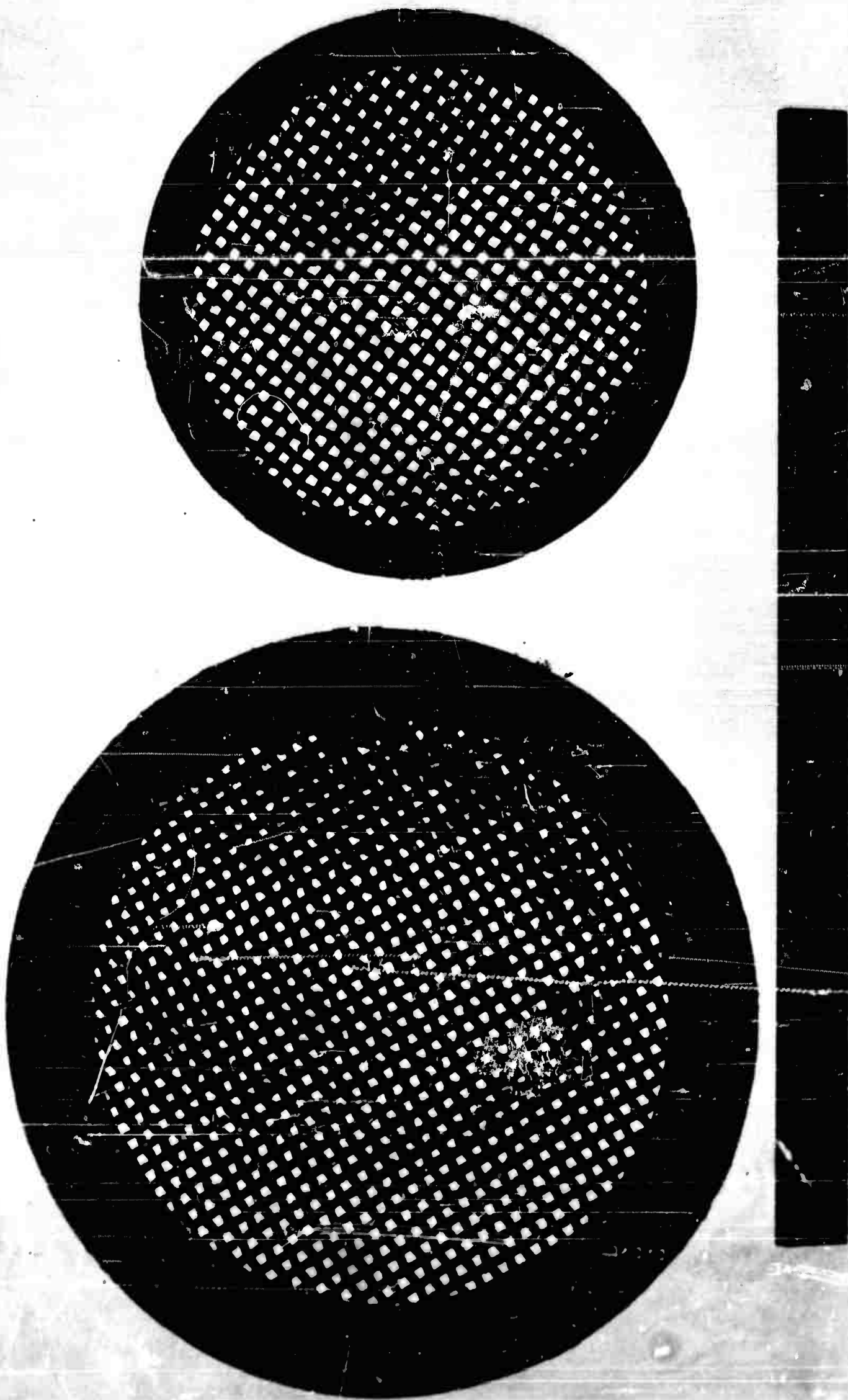
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Solids Deposited Inside the Combustion Chamber Using Untreated
Synthesized Sea Water, Run No. 1



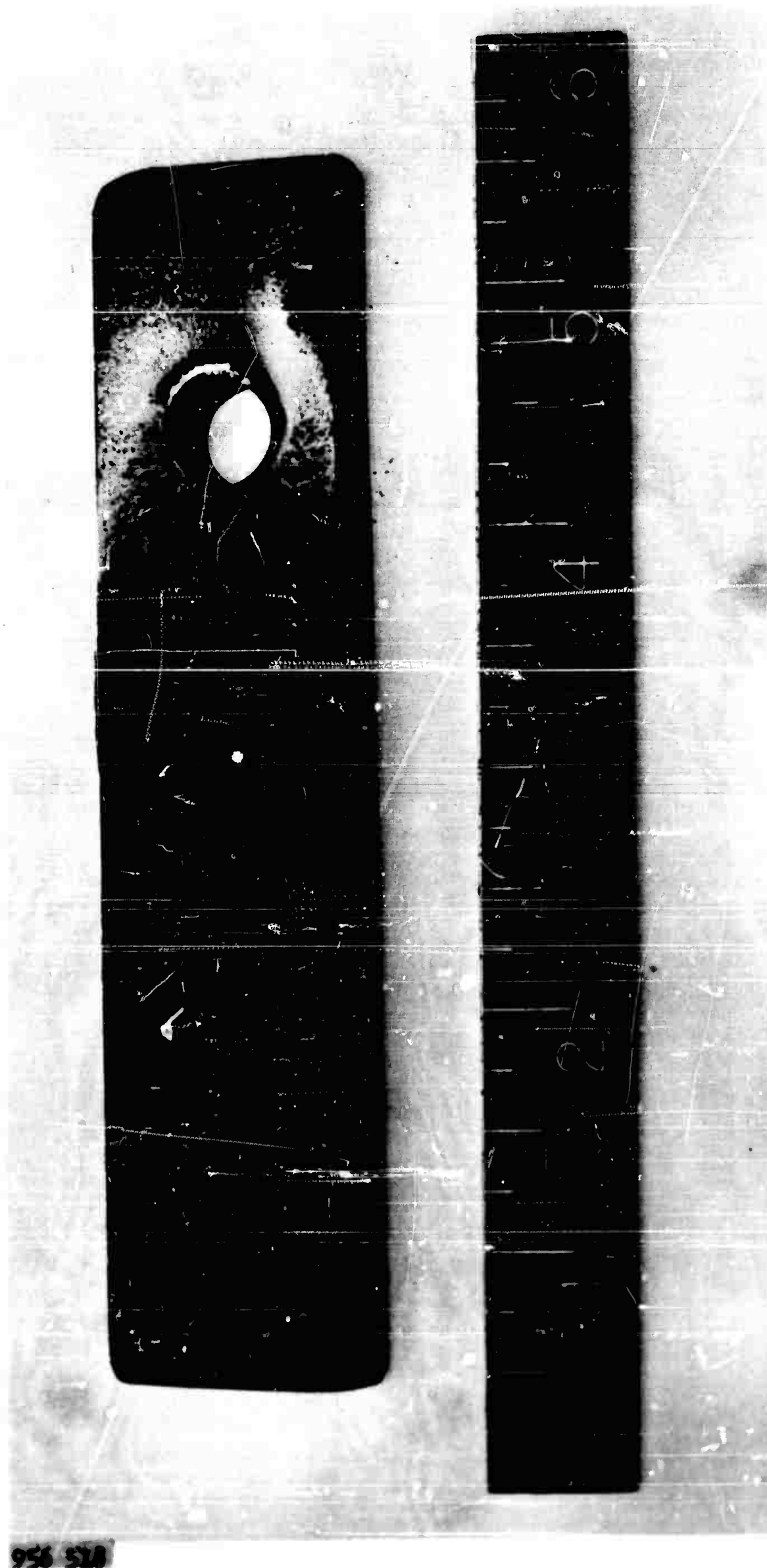
Solids from Untreated Natural Sea Water Deposited in Combustion Chamber, Run No. 8

956 517

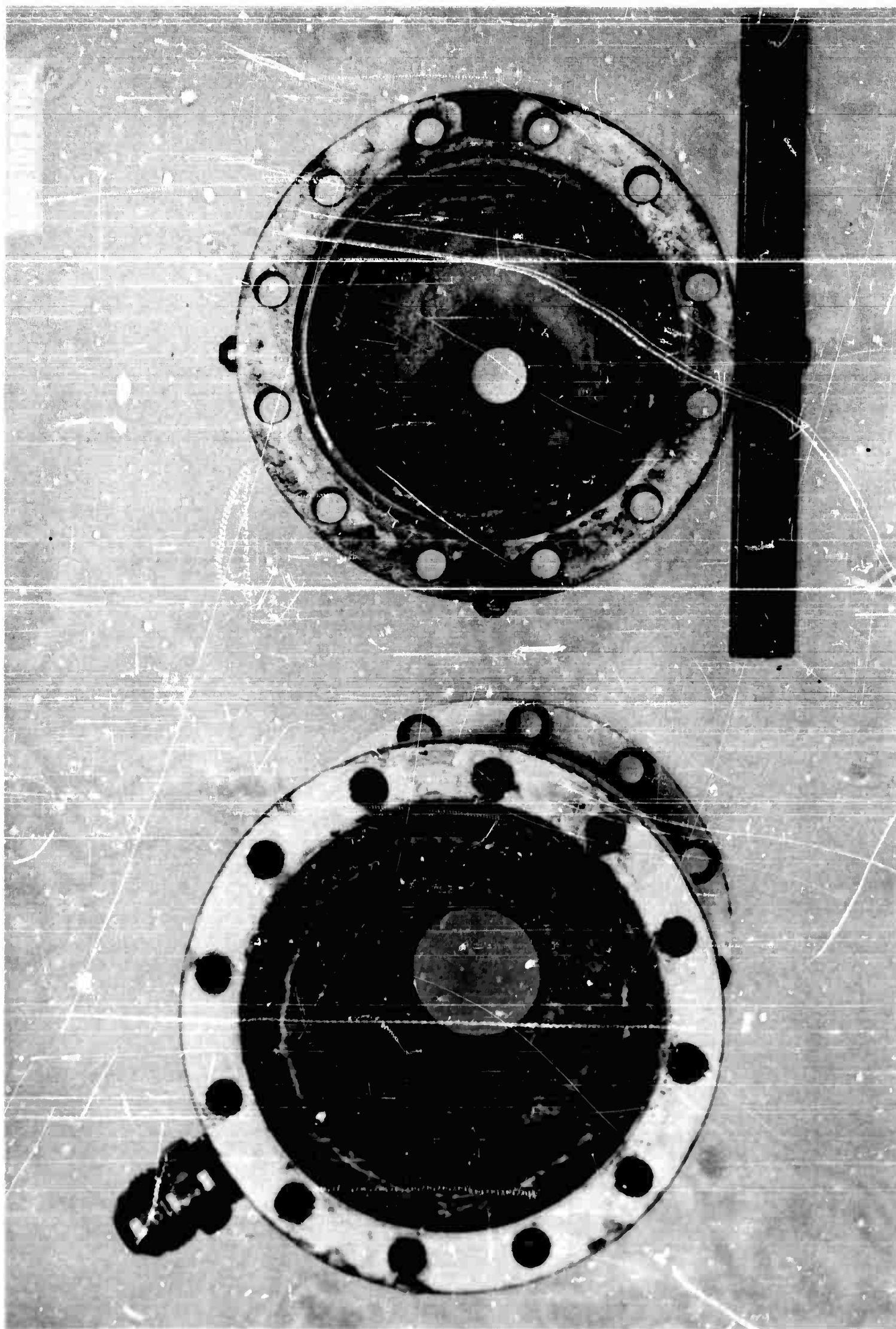


Solids from Untreated Natural Sea Water Deposited on Collector Screens, Run No. 8

956 529

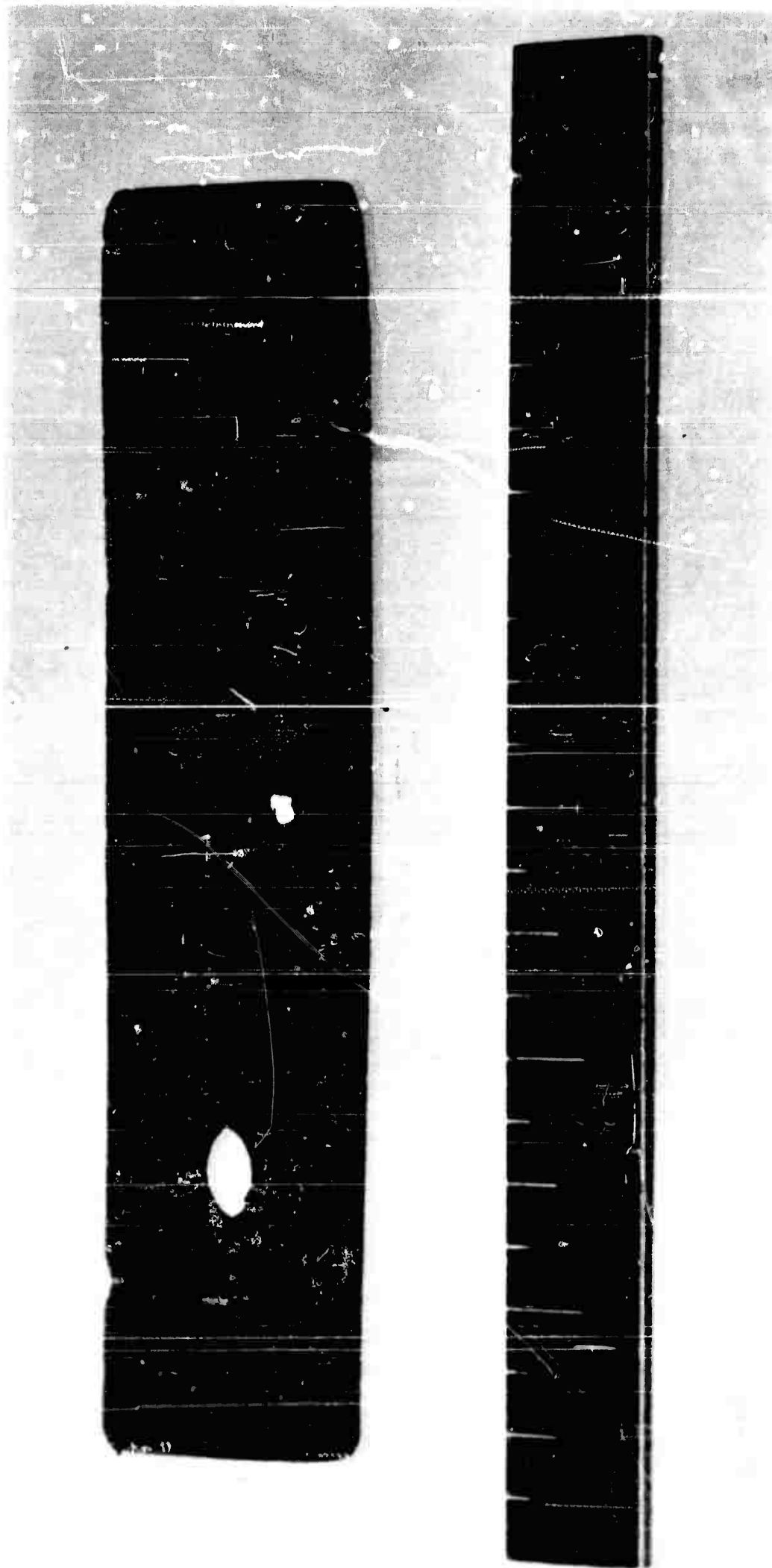


Solids from Untreated Natural Sea Water Deposited on Simulated Turbine Blade, Run No. 8



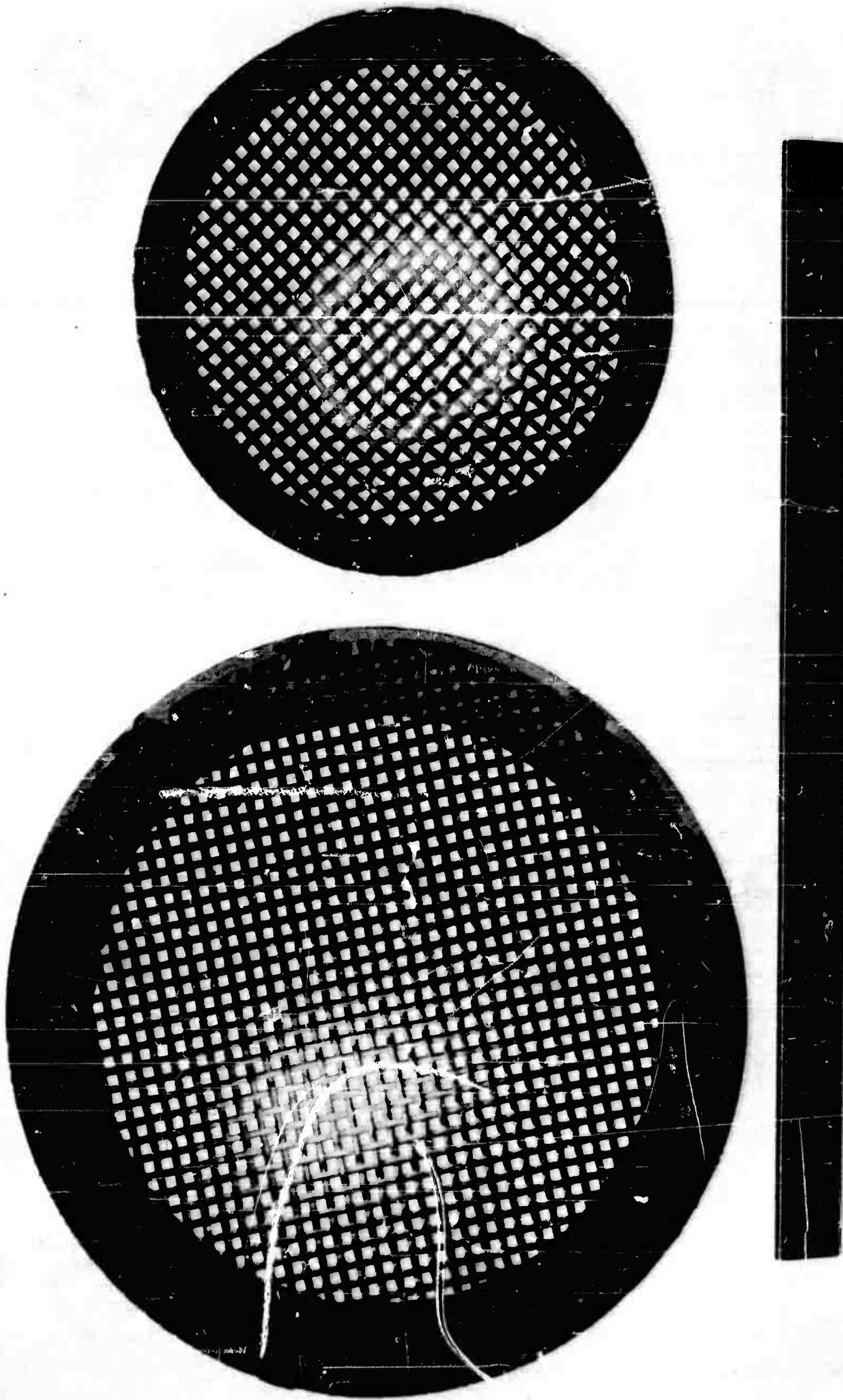
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Solids Deposited Inside Combustion Chamber Using Natural Sea Water, Run No. 13



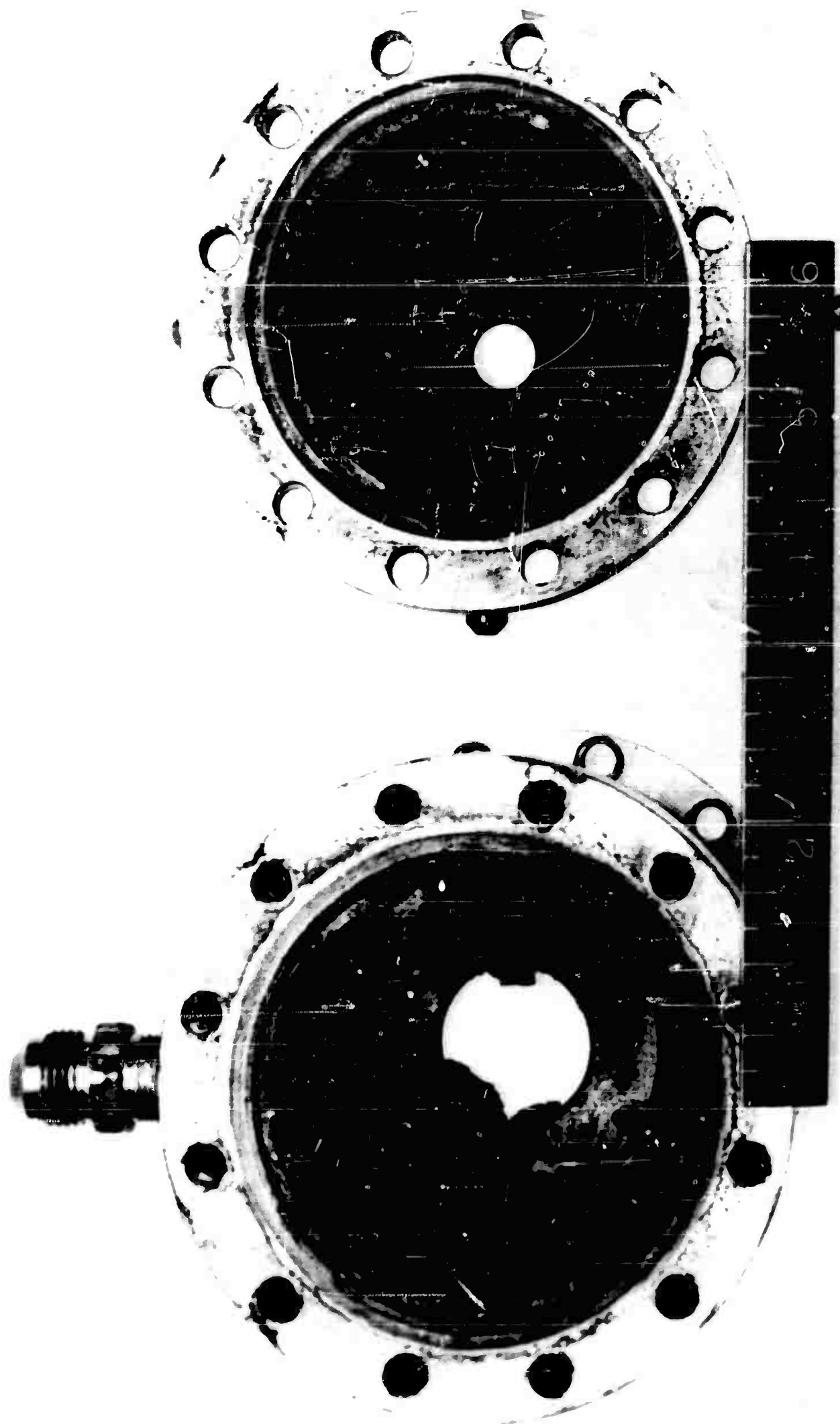
Solids Deposited on Simulated Turbine Blade Using Natural Sea Water, Run No. 13

1056-1538



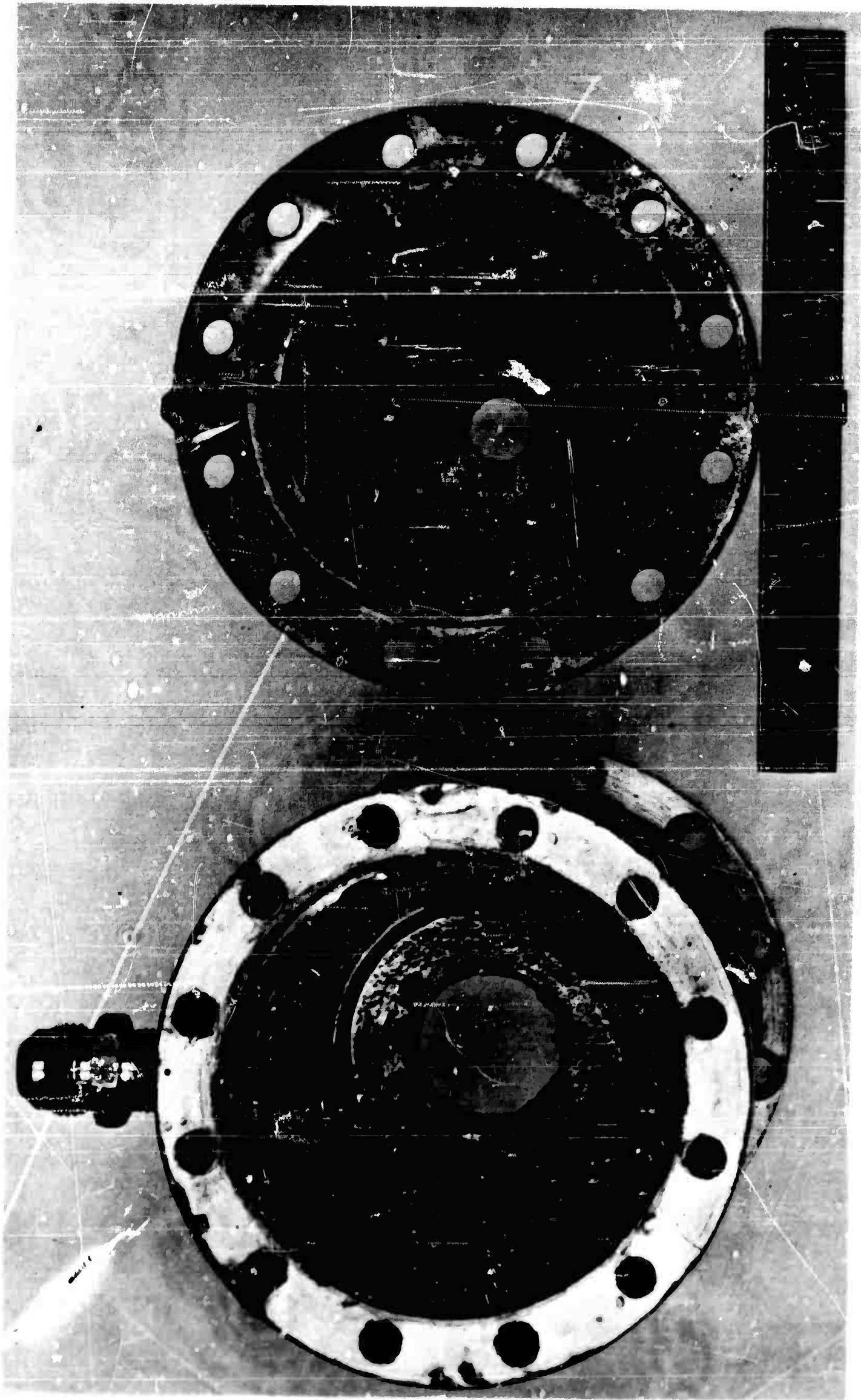
Solids Deposited on Collector Screens Using Natural Sea Water, Run No. 13

1056-1539



Solids Deposited Inside the Combustion Chamber Using Synthesized Sea Water with 50.0% Strong Cationic Exchange

756-1158



Solids from Treated Sea Water Deposited in Combustion Chamber, Run No. 7

956 350



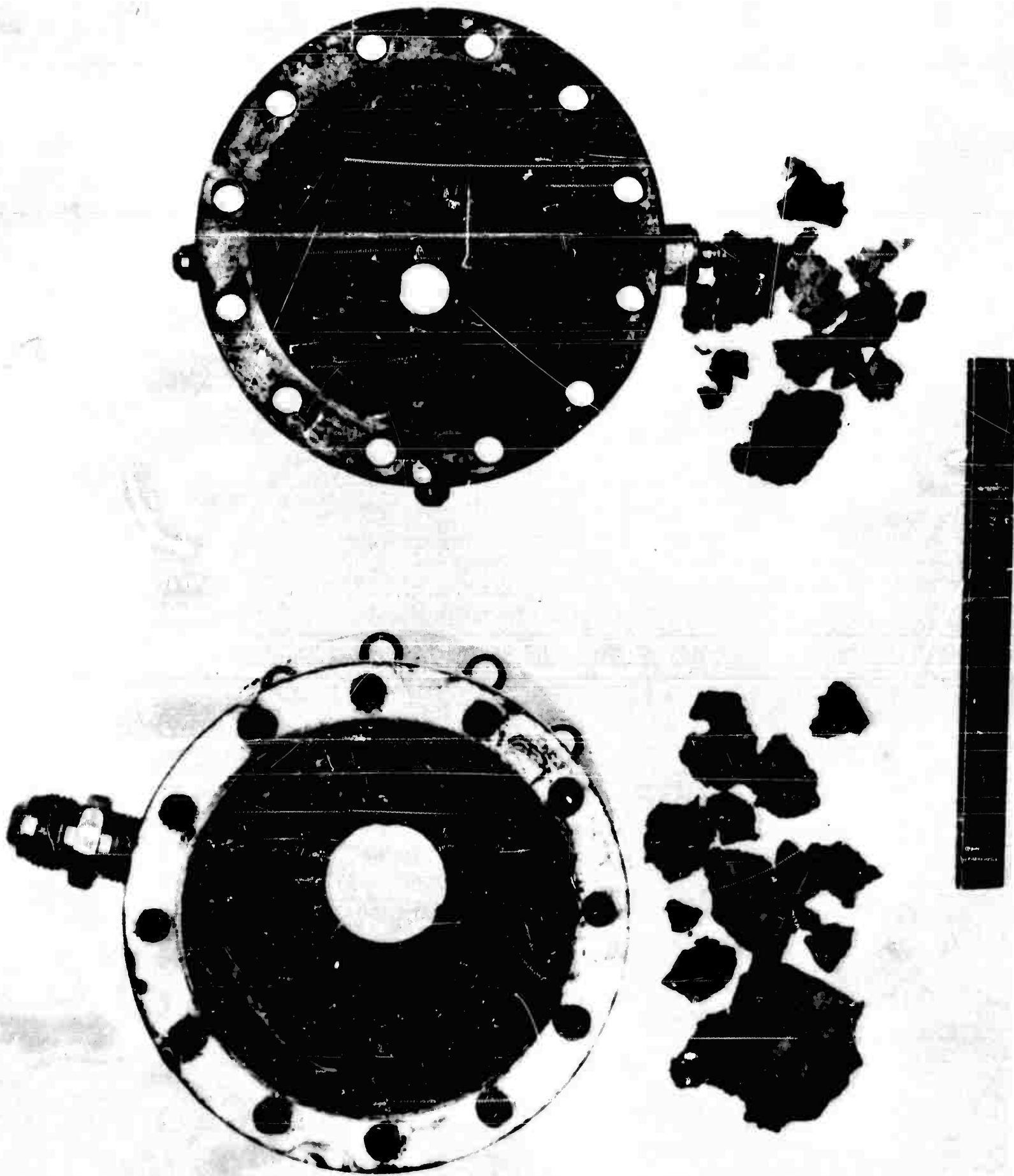
Solids from Treated Sea Water Deposited on Collector Screens, Run No. 7

956 352

956 351

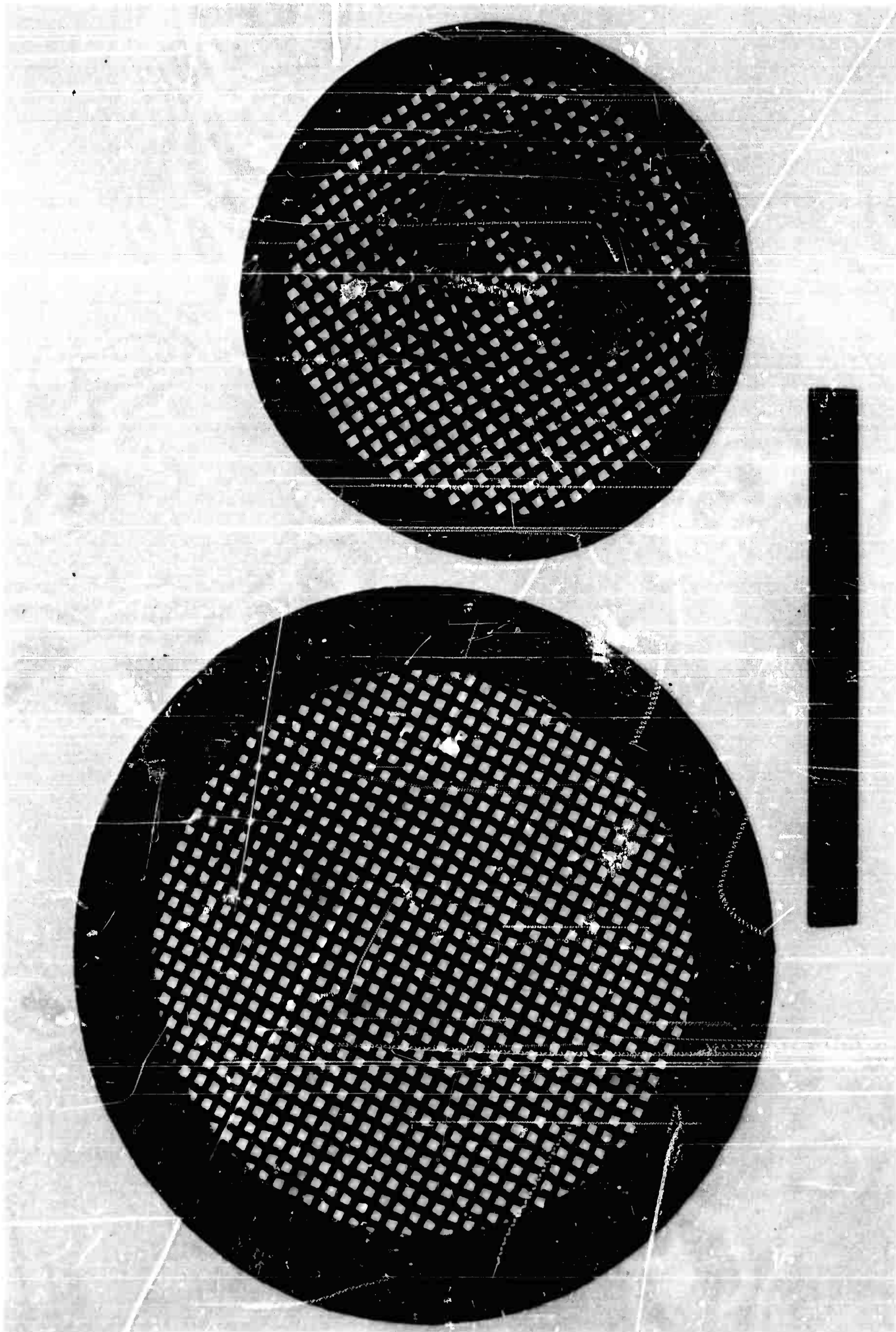


Solids from Treated Sea Water Deposited on Simulated Turbine Blade, Run No. 7



Solids Deposited Inside the Combustion Chamber Using Untreated, Synthesized Sea Water
Graphitic Coating on Chamber Walls, Run No. 6

856-1253

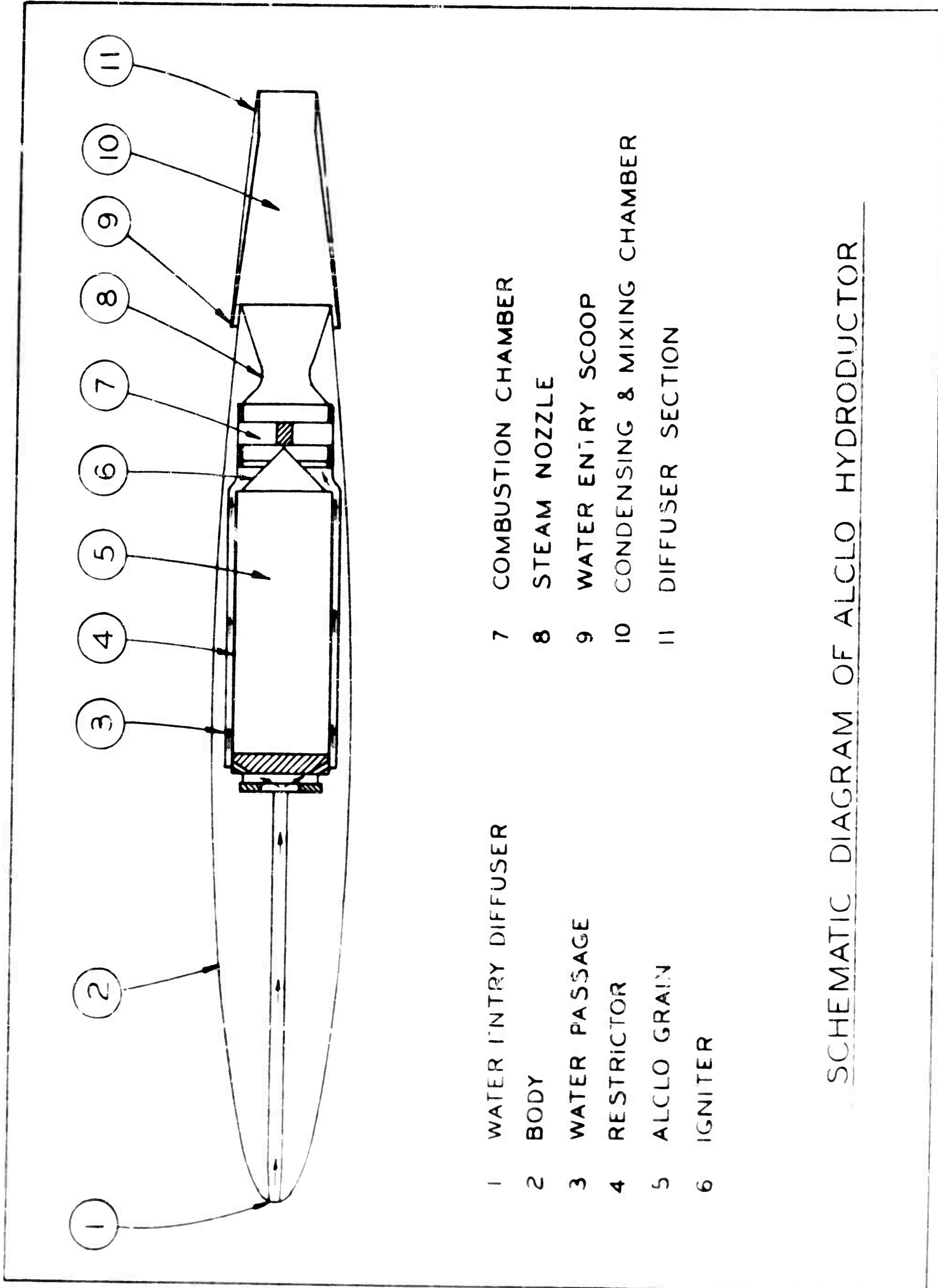


Solids from Untreated Natural Sea Water Deposited on Collector Screens, Run No. 16

1156-1084

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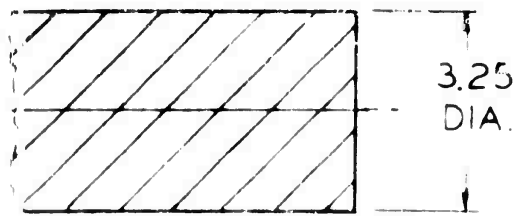
SCHEMATIC DIAGRAM OF ALCLO HYDROJECTOR

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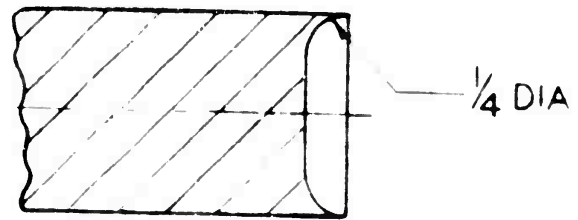


Hydroductor No. 1

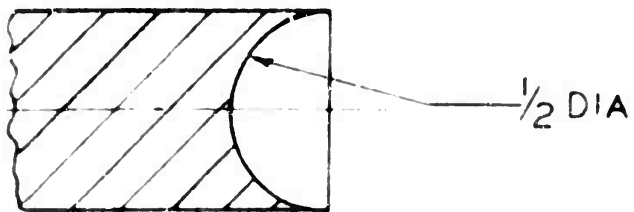
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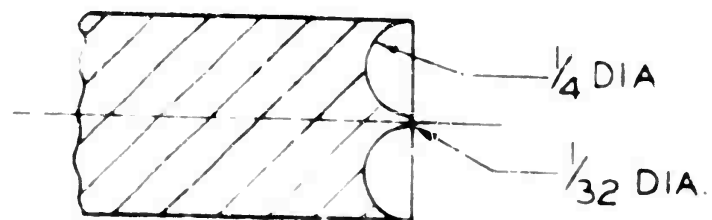
A



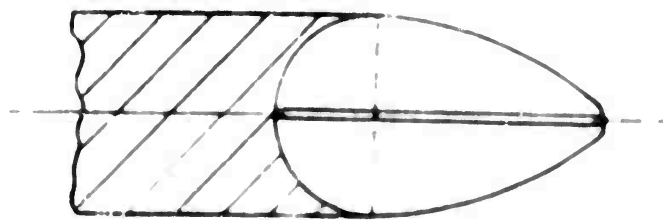
B



C



D

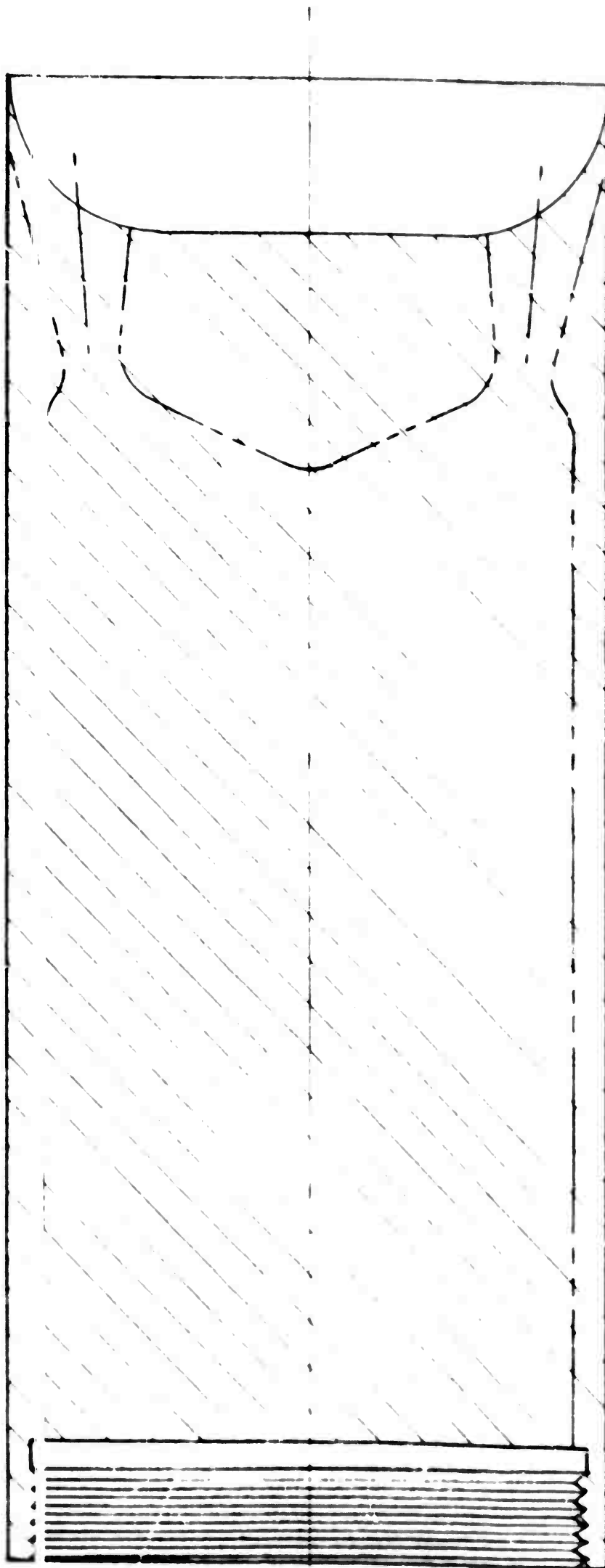


E

SPECIAL AFTERBODY SHAPES

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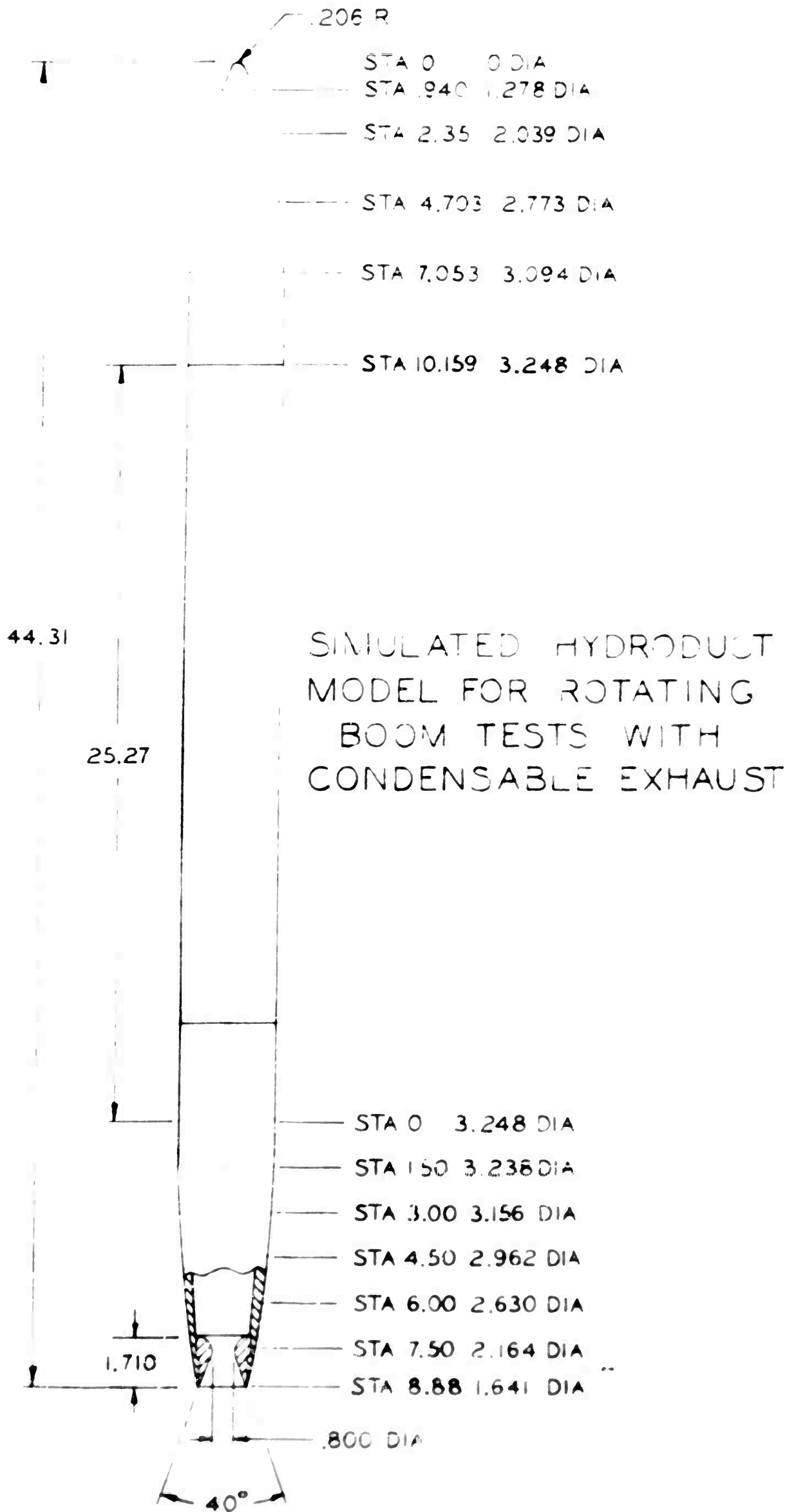
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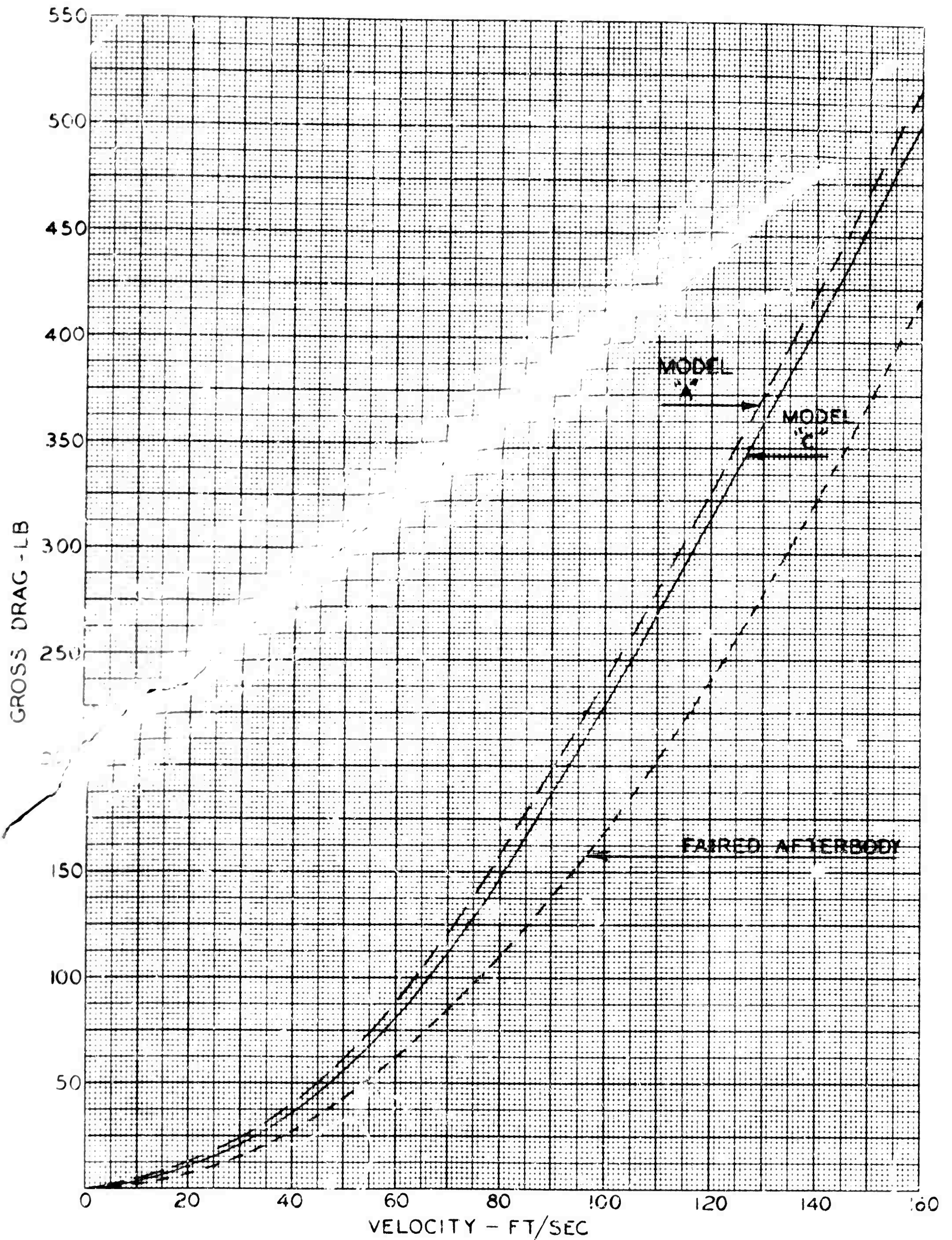


SPECIAL TAIL SECTION
3.25 DRAG TEST MODEL

Figure 21

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COMPARATIVE DRAG