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UNDERWATER PROPULSION DEVICES

FC BAC

Contract Nonr 1863(00)

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Anti-Submarine Warfare Division

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31 March 1959

Report No. 1582
(Final)

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

Contract Nonr 1863(00)

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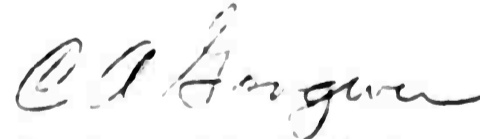
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CONTRACT FULFILLMENT STATEMENT

This final report is submitted in fulfillment of Contract Nonr 1863(00), and covers the period from 6 June 1956 through 31 March 1959.

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I. OBJECTIVE

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

A. The first phase of the program was concerned with establishing the design of the free-running ALCLO hydroductor by suitable static and dynamic tests so that the depth insensitivity of the hydroductor could be proved.

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 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 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 studied and investigated.

II. SUMMARY

A. HYDRODUCTOR

1. The development of the external-condensing hydroductor design was pursued during this program rather than that of the internal-condensing hydroductor. Thus, the problems associated with excessive drag of the internal-condensing hydroductor were avoided.

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II Summary, A (cont.)

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2. Drag tests of various afterbody shapes for the external-condensing hydroductor were made in the ring channel to determine the most favorable configuration. The tests without steam flow were inconclusive, therefore additional tests were made with steam from the accumulator on the boom. The most favorable shape was tested at a variety of operating conditions to simulate various combinations of depth and forward velocity. Performance and operating conditions were compared on the basis of thrust coefficient (C_F) and the cavitation number (σ_k). The cavity parameter numbers calculated from the data obtained in the tests of the most favorable configuration varied from 0.018 to 0.548.

3. The performance was compared of the hydroduct model and the external-condensing hydroductor model used on the rotating boom. The test results of the external-condensing hydroductor model showed net thrust performance values and thrust coefficients that always exceeded the performance values of the hydroduct model.

4. The test of the first free-running external-condensing hydroductor test missile on the ring channel range was not completely satisfactory. This missile had the fins located on the afterbody, and the flow of the high-velocity gases across the fins proved detrimental to the operation of the missile. In addition, the design of the nozzle block proved inadequate to withstand the erosive effect of the exhaust gases.

5. A second design was fabricated and tested with satisfactory performance. This design used a nozzle block fabricated of A4130 steel and the fins were located on the body, just forward of the nozzles.

6. On the basis of this design, five test missiles were fabricated for firing on the deep-water range. A 700-ft vertical range was set up using the facilities of the Navy Electronics Laboratory calibration barge and the other facilities at the David Taylor Model Basin Field Station at Bayview, Idaho. The test conditions were varied by increasing the launching velocity and also by changing the shape of the afterbody on the external-condensing hydroductor test missile. The most satisfactory performance was obtained with the test configuration having the short afterbody and the highest launching velocity. A relatively constant velocity was maintained to a depth of 254 ft.

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II Summary (cont.)

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B. SEA-WATER DILUENT PROGRAM

1. 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. Several approaches to the problem were investigated, either singly or in combination. Among them were the following:

- a. Cationic-exchange treatment of the sea water
- b. 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
- c. 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.

Et 2. 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. Additional tests were made of various designs of cationic-exchange treatment equipment. Test results showed that approximately 0.63 cu ft of Amberlite IR-120 resin would be required to completely process 40% of the sea-water diluent flow required by the Torpedo Mk 16-6 engine. It was estimated that the solid deposits could be controlled satisfactorily if 40% of the salts could be eliminated by the cationic-exchange treatment.

3. This program was curtailed by the contracting agency because work conducted at another laboratory appeared to offer a satisfactory solution to the immediate need for the use of sea water as a diluent.

C. SUBMARINE POWER-PLANT FEASIBILITY STUDY

The results of this study program showed that a small chemical power plant using diesel fuel and 90% concentrated hydrogen peroxide as the propellants with sea-water diluent is feasible for use in a small high-speed submarine.

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II Summary, C (cont.)

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The performance of such an arrangement with a condensing system on the turbine exhaust was calculated to be 6.29 lb of expendables per shaft horsepower hour at the surface and 7.04 lb of expendables per shaft-horsepower hour at 1000-ft depth. All the major components for a 1900-shp power plant could be housed in a space 3 ft in diameter and 3 ft long.

III. CONCLUSIONS AND RECOMMENDATIONS

A. HYDRODUCTOR

1. The net thrust performance of the best model external-condensing hydroductor was very satisfactory, and this configuration was recommended for use as the basis for the design of a free-running test missile. This conclusion was based on the test data, which provided the following information:

a. This model had thrust values that were very uniform (little variation with velocity) over a range of cavity parameter numbers from 0.018 to 0.548. This variation in cavity parameter represents the variation of the velocity of the missile and depth of operation, i.e., 190 ft/sec at a 5-ft depth to 250 ft/sec at a 500-ft depth.

b. The basic drag of this hydroductor model was compared with that of the hydroduct and was found to be very similar.

c. Under the same test conditions on the rotating boom, this model had net thrust values that always exceeded those of the hydroduct model.

2. The performance of the first design of the free-running, external-condensing hydroductor test missile was not satisfactory when check-fired on the short ballistic range in the ring channel. The test data and examination of the missile showed that the fin location on the afterbody was not satisfactory, and that the nozzle block would have to be more adequately protected against erosion.

3. The study of the stability of the free-running body showed that the fins could be relocated on the tail section of the missile ahead of the nozzles and afterbody.

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III Conclusions and Recommendations, A (cont.)

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4. Results of the static pit tests of the interior configuration of the motor showed that satisfactory performance was obtained (a) when the products of the reaction from the ALCLO grain were more thoroughly mixed with the steaming water by the addition of a cross-type turbulator, (b) when the nozzle block was made of A4130-alloy steel instead of aluminum, and (c) when the torch-type igniters were fabricated with copper jackets so that there were no chunks of igniter-case material to clog the small exhaust nozzles.
5. The performance of the second design of the free-running, external-condensing hydroductor test missile was satisfactory when check-fired on the ring-channel range. The three-rail launcher proved to be satisfactory for launching this test missile, and the flight of the test missile was stable.
6. The primary performance characteristic that was being tested on the deep-water range at Lake Pend Oreille was the ability of the test missile to maintain a relatively constant velocity as the depth increased. The increase in launching velocity on two tests appeared to improve the free-running velocity of the test missile. The test in which the afterbody shape was changed and the launching velocity increased, showed the greatest range of depths over which a relatively constant velocity was obtained.
7. There was an indication of increased velocity from the 88-ft depth to the 148-ft depth for one test. The conclusion drawn from this is that the longer afterbody shape was better for this velocity-depth relationship than was the shorter afterbody. While the shorter afterbody might not permit as high a velocity nearer the surface, its use will produce a more-constant velocity to greater depths. Additional tests will be necessary to obtain adequate data to substantiate this conclusion.
8. The deep-water test program showed that complete performance predictions could not be made on the basis of model studies under simulated operating conditions. The design of the afterbody for most of the tests was based upon the design of the model that performed best in the ring-channel tests. The tests in deep water with this design did not appear to be as satisfactory as did the test with the short-afterbody design. The development tests of a

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III Conclusions and Recommendations, A (cont.)

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motor and test missile of this type should, therefore, be conducted on a deep-water range, under actual operating conditions.

9. The shape of the fins on the hydroductor was changed, and the stability of a test missile of this configuration had not been proved by range tests. The stability of this configuration (with the smaller-fin area) appeared to be adequate in all of the hydroductor tests. The range did not contain instrumentation to determine the trajectory of each test missile, but the flight paths were sufficiently true so that the test missile passed close enough to all of the time-distance loops to produce time signals.

10. It is recommended that additional testing of the external-condensing hydroductor be conducted on the deep-water range. Test missiles with various afterbody shapes should be range-fired in order to determine which will have the least change in velocity over the depth available on the range. These afterbody shapes should vary in configuration, from the regular one tested in the above program to very short ones, such as would be represented by a hemisphere.

11. Several hydroduct test missiles should be range-fired under the same launching conditions as the hydroductor test missiles, so that comparative performance can be obtained.

12. The use of the recoilless-gun launcher on the deep-water range program should be re-studied. It is possible to obtain launching velocities of approximately 220 ft/sec with this launcher, when the missile weight is 33 lb. The effect of missiles, such as the hydroductor, weighing 56 lb should also be studied. Before using this launcher on the deep-water range, the hydroductor with the smaller fins should be test-fired in the ring channel in order to prove that all aspects of the launching are satisfactory.

13. It is suggested that future range programs, using the facilities of the Navy Electronics Laboratory calibration barge, use only time-distance loops of the 12-ft size. The smaller loops are too susceptible to damage. The larger loops cannot be handled by the power equipment in the space available inside the well of the barge. Other provisions, such as a recovery net at the bottom of the range, might be added to the range system, if power equipment could be used for the installation of the complete system.

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III Conclusions and Recommendations (cont.)

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B. SEA-WATER DILUENT PROGRAM

1. Test results indicate that, of the methods tried for the use of sea water as a diluent, the most satisfactory operation was obtained by using a strong cationic-exchange treatment of the sea water. Positive benefits can be obtained by the use of this method, and the required equipment for torpedo use is small. This indicates that designs of the future could be even smaller, or that a torpedo of the same size could have increased range.
2. The use of additives with the sea water or fuel in an attempt to change the nature of the solid deposits did not produce any positive results. This technique usually increased the amount of solids that were carried through the system, even though the nature of the solid deposits was changed slightly. It is recommended that no further effort be expended on this technique.
3. It is recommended that development work on the cationic-exchange treatment technique be continued. Further test work is needed to determine the minimum requirement for the cationic-exchange treatment of the sea water so that the amount of solid deposits can be properly controlled. This work should include additional tests at various combustion-chamber temperatures. Further, complete torpedo engine tests should be conducted to demonstrate satisfactory passage of the combustion products through the turbine and exhaust system. The program should continue to include tests with 70% E hydrogen peroxide and alcohol as well as tests with 90% hydrogen peroxide and diesel fuel, since both propellant systems are important.
4. It is recommended that the results of the tests and programs conducted by all agencies to determine the techniques or requirements for using sea water as the diluent in hydrogen peroxide engines be thoroughly reviewed. The peroxide engines of the future will probably be using highly concentrated hydrogen peroxide and a fuel such as diesel oil. The performance advantage to be gained by the use of sea water as the diluent warrants the continuation of a program to study this problem, provided that a satisfactory system has not been completely determined for the higher-performance engines.

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C. SUBMARINE POWER-PLANT FEASIBILITY STUDY

It was concluded that it is feasible to design and develop a small chemical power plant for a small high-speed submarine. This power plant should use 90% concentrated hydrogen peroxide and diesel fuel as the propellants with sea-water diluent. For best performance with varying depth of operation, a condensing system should be used that consists of a condenser on the turbine exhaust, a condensing water pump, and a "froth" compressor pump for discharge of the mixture of water and carbon dioxide. It is feasible to design this power plant so that it will be operationally convenient, simple, reliable, and entirely safe. It is recommended that further theoretical and experimental work be conducted on the reduction or elimination of noise for such a power plant. In addition, it is recommended that development of such a power plant be initiated so that more complete performance data and specifications would be available for incorporation into the design of a small high-speed submarine.

IV. HYDRODUCTOR

A. HISTORY OF DEVELOPMENT

1. An underwater missile such as the ALCLO 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 ALCLO 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 1.

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IV Hydroductor, A (cont.)

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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 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 1.

3. Several free-running tests were made of the 4.5-in.-dia ALCL0 hydroductor test missile (see Figure 2) under sponsorship of the Armament Branch, Office of Naval Research, Contract Nonr 1002(00). The 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 2, 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

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IV Hydroductor, B (cont.)

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sufficient water was not being forced into the condensing section for proper operation of the motor, or that both of these conditions prevailed. It was possible that the excessive drag of the internal-condensing hydroductor configuration (Figures 1 and 2) 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 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.

An approach to the solution of this problem was to be made by studying and testing an external-condensing hydroductor configuration (schematically shown in Figure 3). 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 because of 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.

C. TEST PROGRAM

1. Drag Tests

a. The first step in the testing program was to determine whether there is significantly less drag for any particular afterbody shape. In addition to a completely faired afterbody (for reference purposes), the tail-section shapes shown in Figure 4 were tested. The basic model used for the drag tests was the 3.25-in.-dia test model (Figure 5) used in several previous programs. This model is attached to a hollow strut through which steam can

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IV Hydroductor, C (cont.)

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be delivered to the model. For the drag tests, the tail section of the model was replaced by sections of the experimental shapes without 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.

b. The drag curves obtained from the tests of Model A, Model C (see Figure 4) and the faired afterbody, are shown in Figure 6. 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 7 shows the difference between the drag of Model A, Model D, and the faired afterbody. Drag tests of afterbody shapes B and E (see Figure 4) were also made on the rotating boom in the ring channel and the drag curves obtained were very similar to those obtained on Models C and D. Microflash photographs made during these drag tests are shown in Figures 8, 9, 10, and 11. The data from all of these tests did not show any striking evidence that one afterbody shape would be more feasible than another for use with the external-condensing hydroductor. It was hence concluded that model tests, using steam, would have to be conducted to furnish the desired information.

2. Performance Tests with Steam

a. Using the rotating boom, performance tests were made of various external-condensing hydroductor models. The nozzle block and afterbody configuration for each model is shown schematically in Figures 12 and 13. Each block has 20 small nozzles in an annular ring. The combined throat area of these nozzles is 0.50 in.², the same as that of the hydroduct model (Figure 5) used for previous tests and presently available for comparison of performance. To obtain comparative performance data, steam was supplied from the accumulator on the rotating boom through a hollow strut to the model. Different operating conditions were simulated by making tests at various velocities and by also varying the

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maximum stream pressure available from the accumulator. The test data, which included gross drag of the model and strut, steam pressure (P_c) in the model just forward of the nozzles, rotating boom speed, and the various pressures on the afterbody or nozzle block, were recorded on an oscillograph tape. Microflash photographs were also taken of some of the models at various operating conditions to correlate pictures of the external flow with the performance data.

b. Initial tests were made of external-condensing hydroductor Models X3, X4 and X5 to determine whether there were marked differences in their performance. For these tests, only a single pressure point was used, at the end of the afterbody or at the center of the nozzle block. Figure 14 shows the data obtained on one of the test runs of Model X3. The numbers at the top of this performance curve indicate the time during the run when microflash photographs were taken of the model. Some of these photographs are shown in Figures 15, 16, 17, and 18. During the initial phase of this test, when steam pressure is relatively high, the motor is running in a manner similar to a hydroduct. During the middle phase of the test run, at an elapsed time of 23 sec, the steam pressure in the chamber has been reduced considerably but there is an appreciable increase in the net thrust of the motor, as shown by the large dip in the drag curve. The external flow of condensed steam and water is collapsing on the afterbody, as shown by the increase in rear-stagnation pressure (see microflash photograph No. 6 - Figure 18). These are the effects that were investigated in this part of the program.

c. A performance curve for Model X4 is shown in Figure 19. Microflash photographs were taken during this test at the time intervals shown by the numbers at the top of the performance curves. Some of these photographs are shown in Figures 20, 21, and 22. A single pressure tap was drilled in the center of the nozzle block. The effect of reduced drag, because of collapse of the flow on the rear of the model, was not appreciably evident in this test. The pressure on the center of the nozzle block, inside the annular ring of the nozzles, increased while steam was flowing but did not attain significantly positive values as did that of Model X3. Model X4 was altered by machining the button from the center of the nozzle block as shown in Figure 23. Performance data on this model (X5) was very similar to the data obtained on Model X4.

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d. Tests were made of the external-condensing hydroductor Models X6, X7, and X8, and the performance of each of these models was compared with that of Models X3, X4, and X5. For the test of Model X6, only a single pressure tap was used at the center of the nozzle block. For the tests of Models X7 and X8, five pressure taps were drilled in the afterbody at the points shown in Figures 24, 25, and 26. Data obtained from some of these tests made at various velocity and steam-pressure conditions are shown in the curves of Figures 27 and 28. The cavitation parameter (σ_k) was calculated for the minimum pressure of the cavity, as recorded from pressure taps No. 3 and 4. The cavitation parameter is defined as

$$\sigma_k = \frac{P_\infty - P_k}{\frac{1}{2} \rho V_\infty^2}$$

where

P_∞ = pressure in undisturbed fluid

P_k = pressure in open cavity regardless of the gas with which cavity is filled

ρ = density of liquid

V_∞ = velocity of undisturbed flow

e. From the test data, calculations were made of the thrust coefficient, C_F , at various values of chamber pressure. To obtain the net thrust value to use in the calculation of the thrust coefficient ($C_F = F/P_c A_t$), it was first necessary to determine the basic drag curve of each model. This curve is given in Figure 29. The values used to plot the curve were obtained from the various tests and then corrected to account for the difference in drag before the steam was turned on and during the actual test run. The correction was figured as a suction drag on the model and was calculated by multiplying the pressure reading at pressure tap No. 5 (just aft of the exit plane of the nozzles) by the area of the exit section of the nozzles. This value was then subtracted from the drag reading at time zero (before the steam was turned on) to give a more realistic value of the drag during operating conditions. The difference between this basic

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drag reading and the drag reading at various times during the test was taken as the net thrust of the unit. The calculated values of C_p were plotted on the performance-data curves of Figures 27 and 28.

f. Because there is a great deal of data plotted on the performance curves (Figures 27 and 28), a brief explanation of these curves follows:

(1) The values shown during the time from 0 to 5 sec are the values obtained just before the steam valve is opened from the accumulator on the rotating boom. During the next several seconds there were severe transient effects, primarily caused by air being in the steam line to the model, and significant data could not be obtained. As the steam flows through the model, the steam line, mounting strut, and model are gradually heated. At the same time, the chamber pressure (P_c) builds up in the model until a maximum is reached. This maximum value is primarily a function of the steam-pressure-regulator settings as the steam accumulator is heated to the same temperature for each test run. The chamber pressure then decays as the steam accumulator is being exhausted.

(2) Drag values are initially high, as shown during the time from 0 to 5 sec (before the steam is turned on), because there is no thrust. As the steam flow builds up, thrust increases and is measured as a decrease in drag. The drag therefore decreases to a minimum, and increases again as the steam flow from the accumulator decreases.

(3) The other pressure measurements, P_1 through P_5 , indicate the variation in the pressure field around the afterbody as the steam flow changes during a particular test and also as the velocity is varied for different tests. The relation between the pressure on the afterbody and the flow pattern of steam and water about the afterbody can be seen from Figures 14 through 18. Figure 14 shows the performance curves for the Model X3 hydroductor at a velocity of 140 ft/sec (see Figures 12 and 25). The curve marked P_{RS} is the data from the pressure tap at the aft end of the afterbody. The numbers at the top of the figure indicate the time during the test when microflash photographs were taken of the model. Some of these photographs are shown in Figures 15 through 18. At an elapsed time of approximately 23 sec, the external flow of condensed steam and water collapses on the afterbody. This is shown by the increase in pressure at the rear stagnation point (also see microflash photograph No. 6, Figure 15).

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g. Tests were made to confirm the conjecture that the thrust of the steam-powered hydroduct model (Figure 5) on the rotating boom was independent of the velocity of the model. Data from these tests at the various velocities and at the same chamber pressure (P_c) are shown in Table 1.

3. Discussion of Ring-Channel Tests

a. The performance data at maximum chamber pressure for all of the external-condensing hydroductor models tested is listed in Table 2. In addition to the net thrust of each model at maximum chamber pressure, the thrust coefficient was determined so that a comparison can be made of the performance of each model, even though the maximum chamber pressure was different. The following conclusions were drawn from the data obtained:

(1) The thrust for the hydroduct model did not vary appreciably with changes in test velocity.

(2) The external-condensing hydroductor models with an afterbody (Models X3, X7, and X8) all showed better performance than those models without an afterbody (Models X4, X5, and X6).

(3) The net thrust values for the Model X7 hydroductor were more uniform (i.e., they showed less variation with velocity) than the values obtained for either the Model X3 or X8 hydroductor. The cavity parameter numbers calculated from the data obtained in the Model X7 tests varied from 0.018 to 0.548. This variation in cavity parameter number represented the variation of the velocity of the missile and depth of operation, i.e.: from 190 ft/sec at a 5-ft depth to 250 ft/sec at a 500-ft depth.

(4) The basic drag data of the hydroduct and the hydroductor models were compared. At the higher velocities, the drag of the hydroduct and the hydroductor Models X3 and X7 were very similar (see Figure 29).

(5) Under the same test conditions on the rotating boom, the Model X7 external-condensing hydroductor had net thrust performance values and thrust coefficients that always exceeded the performance values of the hydroduct model on the rotating boom. The data obtained with the Model X7 hydroductor indicated that this configuration was the most suitable of all the models tested for producing a uniform thrust vs drag relationship over a wide range of operating conditions.

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4. Preparation for Deep-Water Tests

a. The results of the test program were discussed with representatives of the contracting agency, and it was decided to plan for deep-water range tests of a free-running, external-condensing, hydroductor test vehicle. The availability of the facilities at Lake Pend Oreille, Idaho (under the direction of the David Taylor Model Basin and the Navy Electronics Laboratory) in addition to the depth of the water there, made this a suitable test site and preparations for deep-water tests were initiated.

b. The design of the free-running test vehicle (see Figure 30) was based on the Model X7 rotating-boom test model. The fins were located on the afterbody instead of on the tail section so that the stability coefficient of this test missile would be similar to that of previously tested missiles. Detail drawings were prepared, and five test missiles were fabricated.

c. One test missile, shown in Figures 31 and 32, was assembled for use on the ring-channel range. This missile served to check out the firing sequence and to verify further the performance of this round before assembling the other test missiles. This test vehicle was loaded with a short-increment ALCL0 grain (burning duration 0.25 sec), and prepared for check testing on the short ballistic range in the ring channel. Four torch-type ALCL0 igniters were used for the ignition of this grain. In order to expedite the complete range testing program, this configuration for the free-running test missile was assembled for ring-channel operation without making any additional static test-pit firings. The short ballistic range and the recoilless-gun launcher are completely described in References 6 and 7.

d. The test missile was launched from the recoilless-gun launcher, and data from the length of the ghost image on the microflash picture (shown in Figure 33) indicated the approximate velocity was 215 ft/sec. This photograph also shows that ignition was very rapid, and there is a possibility that an adequate amount of water was not available for the proper formation of steam at that time. The three selected frames from the high-speed motion-picture film were taken with the Fastax camera equipped with a 12-mm lens (see Figure 34).

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This film showed the missile actually hitting loop No. 4 in the range. The missile was traveling at a constant velocity of 163 ft/sec through the field of view of the camera. The motion of the missile appeared to be a spiral of about a 3-ft radius. The spin rate was considerably higher than that observed on previous tests of the internal-condensing hydroductor or the hydroduct. This higher spin rate could possibly be attributed to the high-velocity flow of gases across the fins on the afterbody (see Figure 35). This photograph is a print from the film of the Fastax camera with a 50-mm lens. There was still some flame from the nozzles evident in these motion pictures. An examination of the missile after the run showed that there was considerable erosion of the nozzles. This erosion was very uneven, one side having the piers between the nozzles completely eroded. This could cause a serious misalignment of thrust, and produce the spiral type of trajectory shown in the motion pictures. Two of the fins had their leading edges burned slightly by the flame for a distance of about 0.5 in. outward from the afterbody. This could have occurred during the initial phase of the test run, since the microflash photo shows extensive flame coming out of the nozzles.

e. The time-distance data and average velocity of the missile were determined satisfactorily from the loop system, with two exceptions: (1) Loop No. 4 was cut by the fins of the missile, and (2) the nose of the missile passed too far outside Loop No. 6. This data is shown in the table below.

<u>Loop No.</u>	<u>Distance Between Loops (ft)</u>	<u>Time Between Loops (sec)</u>	<u>Average Velocity (ft/sec)</u>
1	10	0.0540	185
2	10	0.0582	172
3	20	0.1240	161
5			

Apparently, the nozzle block had been eroded enough so that the afterbody section was separated from the missile by the hit on Loop No. 4 (or shortly thereafter). The leading edges of two fins were damaged by the hit on Loop No. 4.

f. As shown in Figure 35, the exhaust products and high-velocity steam completely covered the afterbody of the test missile and also

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quite a bit of the fin area. The test missile was operating at a very low cavitation number, because of the shallow depth of the ring-channel range. It is possible that this high-velocity steam flow over the fins was the cause of the higher spin rate observed on this test. In addition, the effective fin area for stability of the missile was materially reduced, and it is possible that the test missile was in unstable flight.

g. The stability of the free-running, external-condensing hydroductor was computed according to the method described in Reference 8. The stability coefficient was computed on the basis of the fin area in the free water stream (as shown in Figures 34 and 35) and the stability criterion was not satisfactory. In order to improve the stability coefficient, the area of the fins had to be increased or the distance from the center of gravity of the missile to the center of pressure of the fins had to be increased. It was also considered desirable to remove the fins from the afterbody, so that the fins would not be subjected to the higher-velocity exhaust from the nozzle block. The stability coefficient was recalculated, considering the nose of the missile as being fabricated of steel and with the fins enlarged and placed as shown in Figure 36. With these modifications, an adequate free-running stability coefficient was obtained.

h. In order to provide satisfactory fin area, as previously described, it was necessary to increase the span of each fin to 5 in. This prevented the use of the recoilless-gun launcher, because the slotted bore of the recoilless-gun launcher accommodated a missile with a maximum fin span of 4.5 in. It was necessary, therefore, to use the three-rail launcher with the T46 booster rocket for launching the free-running, external-condensing hydroductor test missile. This launcher was used satisfactorily for most of the test firings of the 4.5-in. hydroduct at the Morris Dam facility of the U.S. Naval Ordnance Test Station and accommodated a missile with a 5-in. fin span (see Reference 6).

i. To prevent erosion of the nozzle block, it was decided to increase the mixing of the hot reaction products and the free water by adding a cross-type turbulator between the two turbulator rings, and to fabricate this part of the Type A4130 steel. Further, a button of phenolic material was used on the face of the nozzle block. These modifications are included in the sectional

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drawing of the test missile shown in Figure 36. A series of tests were made with a static test-pit motor to confirm the feasibility of this design change. These tests were reported in Reference 7.

j. Based on this design, the components for another free-running test missile were fabricated. This unit is shown in Figures 37 and 38. The ring-channel range was prepared for the testing of this missile by locating the support frame-work so that the rail-type launcher would be properly aligned with the ballistic recovery box (see Reference 7).

k. The nose inlet of the test missile was sealed with the conventional aluminum burst diaphragm (used in all of the hydroduct tests), while the exit nozzles were closed with cork and sealed with paraffin (see Figure 38). The lead-in wires for the four igniters were connected in parallel to two heavier wires that were carried through two of the cork seals in the nozzles. These lead-in wires were secured to the launcher so that they would be pulled out of the missile as it was boosted down the launcher rails. This procedure prevented the wires from partially blocking the small nozzles and acting as a trap for the products of the reaction of the ALCL0 grain. The interior configuration of the test missile is shown in Figure 36.

l. When the missile was launched, the booster rocket and the ALCL0 grain were ignited simultaneously. A small amount of slack was available in the lead-in wires to the ALCL0 grain so they would not be broken if the booster ignited first. The booster adapter, which coupled the booster rocket with the test missile, was provided with a rubber-lined socket to seat the afterbody of the missile. The configuration of the test missile prevented the use of shear pins (used in the hydroduct launchings) to restrict the rotation of the missile during the early phases of missile travel in the launcher. The frictional resistance between the rubber socket and the afterbody was not adequate to provide the desired restriction on rotation. The test missile rotated about its longitudinal axis in the launcher. One fin hit a series of bolts at the base of a launcher rail and ripped 1/4 in. off the tip of the fin. With this exception, the launching procedure was satisfactory and the break-rod data on the launcher indicated that the launching velocity was 180 fps.

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m. The photographs of Figures 39 and 40 are prints from the high-speed motion-picture camera with the wide-angle lens, and Figure 41 is a print from the film of the camera with the 25-mm lens. The trajectory of the missile was a tight spiral and the cavitation of the one damaged fin was evident. The average velocity was 179 fps between the loops placed 22 and 32 ft in front of the launcher, and 174 fps between the loops placed 32 and 42 ft from the launcher. The average velocity obtained from the motion-picture film was 179 fps. The test missile had a steel nose with a very dull finish which accounts for the difference in appearance of the nose section and the rest of the test missile in the photographs. The test missile was captured in the recovery box and, with the exception of the damaged fin, was in very good condition.

n. The tests were considered satisfactory, and plans were initiated to conduct deep-water range tests of this external-condensing hydroductor test missile. In order to prevent recurrence of damage to the fin, the arrangement of the launcher rail was changed so that the fin tips could not hit any bolts, and the rotation of the missile about the longitudinal axis was decreased to one revolution every 60 ft rather than one revolution every 30 ft, so that the fins would not rotate enough to touch the rails. The ring-channel test was conducted to check the interior configuration of this test missile as well as the free-running stability of the external configuration. Satisfactory results were obtained on both aspects of the test.

o. A hydroduct test missile that had been previously fired on the Morris Dam range was reassembled, so that comparative performance data could be obtained. This hydroduct is similar to the one shown in Figure 42. Both the hydroduct and the hydroductors were loaded with ALCLO grains having a burning duration of 3.8 to 4.0 sec. The igniter arrangement was the same as that used on the previous hydroductor test, and consisted of four 3/4-in. torch-type ALCLO igniters.

p. A re-examination of the stability coefficient of the external-condensing hydroductor showed that a considerable portion of the front part of the fins could be removed without lowering the stability. This was possible because the center of pressure of the fins moved aft when the area was

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removed from the leading edge, and the slope of the lift-coefficient vs angle-of-attack curve increased because of a more favorable aspect ratio. The contribution to the stability by these two factors compensated for the decrease in fin area. The net effect was to maintain comparable stability and to reduce slightly the overall drag of the missile because of the decreased fin area. Therefore, the fins were modified as shown in Figure 43.

q. Further study of the operating conditions of the test motor revealed that if the test missile maintained high velocity as it traveled in the deeper water, the flow of steaming water would be excessive. A water-flow limiting valve was designed and fabricated for insertion in the water passage in the nose of the test missile. The flow vs pressure-drop characteristics of this valve are shown in Figure 44. For the normal operating flow of approximately 6 lb/sec, very little resistance was added to the water flow by this valve.

5. Preparation of Deep-Water Range and Loading of Launcher

a. The use of the Navy Electronics Laboratory's calibration barge and the other necessary facilities at the David Taylor Model Basin Field Station, Bayview, Idaho, were scheduled for the 2-week period starting 4 August 1958. The loop system for obtaining time-distance data was prepared. Brackets and a hoisting sling were attached to the rail launcher so that the launcher could be placed in a vertical position and the necessary equipment was shipped to the test site. The 12-ft and 18-ft loops were assembled on the dock at the field station, and then transported on a working float to the calibration barge. Because the 18-ft loops were too large to be handled inside the well of the calibration barge, the spreader at the bottom of the loop array and the 18-ft loops were placed in the water by hand from the working float and the out-rigger of the calibration barge. The arrangement of the loops on the deep-water range is shown schematically in Figure 45. The method of installing the loop system was fully described in Reference 9.

b. The launcher was placed in the horizontal position, as shown in Figures 46 and 47, and loaded with the test missile, booster adapter, and booster. Three nylon ropes were attached to the booster adapter, tied with

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light line along the edges of the framework of the launcher, and shackled to the bottom end of the launcher. These ropes were used to arrest the booster adapter and booster housing after they emerged from the launcher rails, so that they would not fall down through the loop system. Carbon break-rods were installed on the launcher, and the stud was placed in the booster adapter at the right position to break the carbon rods. (This arrangement was used to obtain time-distance data as the missile and booster traveled down the launcher rails.) A shear pin was attached through a clevis to the fin of the missile in order to prevent any movement of the missile and booster combination before the booster was fired.

c. When the launcher was completely loaded, it was placed again in the vertical position and the loading rechecked. Figures 48 and 49 show the launcher loaded and being checked prior to its submergence in the water. Figure 48 shows one of the nylon ropes in place along the edge of the launcher framework. Figure 49 shows the clevis and shear pin in place over one fin of the missile, as well as the eye bolts and shackles of two of the nylon arresting ropes. The vertical position of the launcher was checked with a gunner's quadrant, and the launcher was then positioned in the center of the loop system. Two light cotton lines were pulled tight across the corners of the loop system, as shown in Figure 50, and the center of the booster was aligned with the cotton lines so that the launcher would be firing down through the exact center of the loop system.

d. For the first test, the launcher was lowered to a depth of 32 ft at the muzzle, which placed the nozzle of the booster rocket approximately 10 ft deep. Upon firing the first round, the exhaust gases from the booster rocket vented, and the blast threw water over the inside of the barge. Subsequent rounds, therefore, were launched with a muzzle depth of 40 ft. A steel tape was attached to one leg of the support brackets at the top end of the launcher, and the launcher was lowered until the top end was 20 ft deep.

6. Deep-Water Tests

a. The six test missiles were fired with slightly different launching conditions; the variations are listed in Table 3. The water-flow-limiting valve was used in the testing of the first external-condensing hydroductor, and removed for the test of the second one to determine whether this would change the performance of the test missile. This flow-limiting valve was used with all the subsequent hydroductor-test missiles.

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b. The weight of the hydroduct was somewhat less than that of the hydroductor, and compensation was made by changing the booster-adapter weight of the hydroduct so that comparable launching velocities could be obtained. The last three test rounds were fired with lower total launching weights. The weight was reduced by machining off portions of the booster adapter and changing the plug that connected the booster adapter with the booster. (Figures 51 and 52 show the booster adapter as machined for Test No. 5 and 6, respectively. The total launching weights are listed on Table 3.) In addition, two of the booster-arresting lines were eliminated for Test No. 5, and all the arresting lines were eliminated for Test No. 6. This decreased the total drag during the launching phase and therefore increased the launching velocity.

c. Three different missile configurations were tested. These were the hydroduct (Figure 42), the external-condensing hydroductor with the regular afterbody (Figure 43), and the external-condensing hydroductor with a short afterbody (Figure 53). The short afterbody was made by reworking the regular afterbody on a lathe at the NEL barge. The regular afterbody was cut in half, the hole in the center was plugged with a Micarta block, and then the piece was recontoured and polished.

7. Discussion of Deep-Water Test Results

a. The performances of the test missiles are summarized in Table 3.

The average velocities were obtained from the time data of the oscillograph records and the known location of the loops (see Figure 45). The nose of each missile contained two Alnico rod magnets that produced a voltage in the loop as they passed nearby. This signal was large enough to be detected and recorded without amplification.

Loop No. 1 at the top of the range showed an open circuit after Test No. 1. The range was lifted, and it was found that one fin of the missile had severed the loop. The range system was lowered again without replacing this loop.

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Loop No. 6 showed an open electrical circuit at the end of Test No. 4. When the range system was removed from the water after all the tests had been completed, the damage caused by the missile striking the loop was apparent.

b. The arresting lines on the booster and booster adapter functioned satisfactorily in all cases; the same booster adapter was used for all of the hydroductor runs.

c. The booster rocket did not ignite satisfactorily on the hydroduct test, but the igniter of the booster and the ignition of the ALCLO grain in the missile evidently produced enough thrust to shear the retaining pin on the missile and allow the hydroduct to be launched. An examination of the booster rocket after the firing showed a considerable amount of unburned propellant. Facilities were not available to disassemble this unit to determine the amount of unburned propellant.

The hydroduct motor produced enough thrust so that the test missile accelerated from a velocity of approximately 25 ft/sec in the launcher to an average velocity of 96 ft/sec in its flight from 148 ft deep to 178 ft deep. This increase in velocity, when the test missile was not properly boosted, was considered worthy of note. This data indicates that the hydroduct might have satisfactory performance at depths of 175+ ft, and further tests would be warranted.

d. The free-running velocity of the first two hydroductor-test missiles was not as high as desired, and part of the difficulty was attributed to the launching velocity.

The launching velocity for Tests No. 4 and 5 was increased, as shown in Table 3, and more satisfactory velocities of the test missiles were obtained at greater depths. For Test No. 6 the launching velocity was increased again, and the afterbody shape was modified. The best free-running velocity was obtained with this unit. A relatively constant velocity was obtained to a depth of 254 ft on this test run, but thereafter the velocity decreased.

e. An estimate of the duration of burning of the ALCLO grains was obtained from several sound records made by personnel of the Hudson Laboratories, who were doing other work on the NEL barge. The sound-recording equipment

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was not functioning perfectly, and there was some doubt about the exactness of the records, but the indications were that the burning durations averaged approximately 4 sec.

The time-distance data obtained on all of the hydroductor runs was plotted to a flight time of 4 sec, as shown in Figure 54. This data also shows the relatively constant velocity of the No. 4 hydroductor test missile (Test No. 6) down to a depth of more than 250 ft.

f. The stability of the missile was excellent; the missile passed close enough to all loops in at least several cases to give time-distance data. The depth of the last loop was 706.8 ft.

g. The test data did not indicate whether better performance was obtained when the test hydroductor contained the water-flow limiting valve.

D. CONCLUSIONS AND RECOMMENDATIONS

1. The primary performance characteristic that was being tested was the ability of the test missile to maintain a relatively constant velocity as the depth increased. The increase in launching velocity on Tests No. 4 and 5 appeared to improve the free-running velocity of the test missile. Test No. 6, in which the afterbody shape was changed and the launching velocity increased, showed the greatest range of depths over which a relatively constant velocity was obtained.

2. There was an indication of increased velocity from the 88-ft depth to the 148-ft depth for Test No. 5. The conclusion drawn from this is that the longer afterbody shape was better for this velocity-depth relationship than the shorter afterbody. While the shorter afterbody might not permit as high a velocity nearer the surface, its use will produce a more constant velocity to greater depths. Additional tests will be necessary to obtain adequate data to substantiate this conclusion.

3. The deep-water test program showed that complete performance predictions could not be made on the basis of model studies under simulated operating conditions.

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The design of the afterbody for Tests No. 1, 2, 4, and 5 was based upon the design of the model that performed best in the ring-channel tests. The tests in deep water with this design did not appear to be as satisfactory as did the test with the short-afterbody design. The development tests of a motor and test missile of this type should, therefore, be conducted on a deep-water range, under actual operating conditions.

4. The shape of the fins on the hydroductor was changed, and the stability of a test missile of this configuration had not been proved by range tests. The stability of this configuration (with the smaller-fin area) appeared to be adequate in all of the hydroductor tests. The range did not contain instrumentation to determine the trajectory of each test missile, but the flight paths were sufficiently true so that the test missile passed close enough to all of the loops to produce time signals.

5. It is recommended that additional testing of the external-condensing hydroductor be conducted on the deep-water range. Test missiles with various afterbody shapes should be range-fired in order to determine which will have the least change in velocity over the depth available on the range. These afterbody shapes should vary in configuration, from the regular one tested in the above program to very short ones, such as would be represented by a hemisphere.

6. Several hydroduct test missiles should be range-fired under the same launching conditions as the hydroductor test missiles, so that comparative performance can be obtained.

7. The use of the recoilless-gun launcher on the deep-water range program should be re-studied. It is possible to obtain launching velocities of approximately 220 ft/sec with this launcher, when the missile weight is 33 lb. The effect of missiles, such as the hydroductor, weighing 56 lb should also be studied. Before using this launcher on the deep-water range, the hydroductor with the smaller fins should be test-fired in the ring channel in order to prove that all aspects of the launching are satisfactory.

8. It is suggested that future range programs, using the facilities of the NEL barge, use only time-distance loops of the 12-ft size. The smaller

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loops are too susceptible to damage. The larger loops cannot be handled by the power equipment in the space available inside the well of the barge. Other provisions, such as a recovery net at the bottom of the range, might be added to the range system, if power equipment could be used for the installation of the complete system.

V. SEA-WATER DILUENT PROGRAM

A. PURPOSE

One of the better chemical power-plant systems at present uses hydrogen peroxide and a hydrocarbon fuel. While such a plant is relatively efficient, of primary importance is the fact that it is essentially wakeless. 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 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.

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. A literature survey was conducted first which included the 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 10. Other sources were reports from USNOTS, Pasadena, California; the Food Machinery and Chemical Corporation, Becco Chemical Division, Buffalo, New York; and Professor Helmuth Walter, Worthington Pump and Machinery Corporation, Harrison, New Jersey. With this background information as a guide, the diluent problem was investigated in several ways, which included 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 would not occur or could be readily flushed away.

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

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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 55, 56, and 57), developed under Contract NOrd 16510, were used for 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 liner and enzian-ring components to decrease the size of the cooling water passages and thus increase the velocity of the cooling water. Although the main objective of the program was 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 for some of the work during the course of the program. Furthermore, such propellant was on hand, together with vitally needed torpedo components and workshop gear (through cooperation of the Bureau of Ordnance) and its use resulted in a considerable saving of 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. Photographs of the complete thrust-dynamometer test installation are shown in Figures 58 and 59. Figure 60 shows the thrust dynamometer installation, without the exhaust collector system. The three propellant flowmeters (orifice-d/p cell type) are shown on the side of the thrust stand in Figures 58 and 60. (The Annin valves on the meter lines were not used for this program; flows were controlled with Waterman-type constant-delivery valves.)

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

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The stainless-steel sea-water diluent tank is visible at the left in Figure 60, against the wall of the test pit. A small portion of the diesel-fuel tank is visible above the dynamometer (extreme left) in Figure 58. The Mk 16-6 torpedo peroxide and fuel tanks are located inside the steel box at the right of Figures 58, 59, and 60.

3. Special ion-exchange units were installed in the sea-water line on the dynamometer installation for some of the tests (see Figures 58, 59, and 60). The units contained Amberlite IR-120 exchange resin for processing the sea water prior to injection into the combustion chamber. Tests were also performed using only the exchange unit, and measurements were made of the percentage of cationic exchange as a function of time at various sea-water flow rates. The runs with additives were made without the use of the cationic-exchange units. The various chemicals were simply added to the sea water for these tests.

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 harbor sea water contained small amounts of fresh water and colloidal clay. Subsequently, sea water was obtained offshore from Seal Beach and this was used in the later tests. A chemical analysis of all the sea-water samples are presented in Table 4. The sample of sea water used for each test is identified in Tables 5 and 5.

2. A brief description of all tests conducted is shown in Tables 5 and 6. The data regarding the total weight of solids introduced into the system during the test run and the weight of the solids deposited in the combustion chamber and exhaust system are presented in Tables 7 and 8. Brief discussions of some of the tests are covered in the paragraphs below.

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

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a. Tests 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 61 through 67).

b. 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 surfaces of the hardware, 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 Figure 68).

c. 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.

d. Tests No. 17 and 25 are the reference runs (without any diluent treatment) for the tests made with 70% E hydrogen peroxide and 92.5% ethyl alcohol and the two different samples of natural sea water. The solids deposited in the combustion chamber for Test No. 25 are shown in Figure 69. The results of Test No. 25 indicated a similar quality, but slightly larger quantity of solid deposits than were obtained in Test No. 17. This larger quantity can probably be attributed to the lower combustion chamber temperature (1275°F for Test No. 25 vs 1550°F for Test No. 17) and the slight difference in sodium concentration between the two sea-water samples.

e. Several tests were made using different sizes and configurations for the cationic exchange cartridge. The data from Test No. 21, 22, 24, and 26 should be compared with the two reference tests (No. 17 and No. 25). There was a very significant reduction in the solid deposits for Test No. 22 when the cationic exchange bed was increased in size to 12.5-in. dia x 5.5-in. Figure 70 shows the solids deposited in the combustion chamber for Test No. 22. While there was decided improvement in results when the test duration was limited

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

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to 2 min, the results for Test No. 26 showed that the 12.5-in. dia and 5.5-in. cationic exchange cartridge was not adequate for the longer duration tests.

f. Test No. 19 (a control test), and No. 20, and 23 were made with 90% hydrogen peroxide and diesel fuel. The data from Test No. 20 shows that the 6-in.-dia x 6-in. long cationic exchange bed was too small because there was no significant reduction in the amount of solids deposited. When the larger size cartridge was used in Test No. 23, a significant reduction in solid deposits was obtained. A photograph of the combustion chamber after Test No. 19 is shown in Figure 71 and Figure 72 shows the combustion chamber after Test No. 23.

g. A measure of the effect of chamber temperature on the solids deposited is shown by comparing Tests No. 17 and 19. The total weight of solids into the system is greater for Test No. 19 than for Test No. 17, yet the amount deposited is less. Chamber temperatures were 1550°F for No. 17 and 1950°F for No. 19.

h. Special tests of the cationic-exchange process were conducted.

(1) Several tests were made to determine the output efficiency of the strong cationic-exchange beds used for some of the combustion tests described above, and of new bed designs for subsequent combustion tests. For these investigations, samples were taken at specified time intervals from the processed sea water being discharged from each bed. The percentage of sodium exchange was determined for each sample, and this value was taken as the percentage of cationic exchange.

The first test was conducted on the 6-in. OD and 6-in. long bed used for Test No. 20. The percentage of sodium exchange was determined to be 85% at 10 sec and 26% at 120 sec from the start of the run.

(2) Three tests were made with natural sea water flowing through resin beds of two different sizes. The beds of strong cationic exchange resin, Amberlite IR-120 were 12.5-in. OD with lengths of 2.0 in. and 5.5-in. (see Figure 58). The test durations were 2.0 min, corresponding to the usual test run; and 15 min, corresponding to a maximum torpedo running time. The results of these tests are shown on the curves of Figures 73 and 74.

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(3) An analysis of all the test results with the different sizes of strong cationic exchange beds revealed that the percentage of ion exchange at the start of each run should be decreased, and the percentage of ion exchange at the end of each run should be increased (essentially "flattening" the output curve of the bed) to obtain the maximum effectiveness from any given size bed for this application. In order to "flatten" the output curve of the cationic exchange bed, special designs of the bed component were investigated as well as arrangements for bypassing a portion of the sea-water flow around the bed.

(4) An ion-exchange test was made to investigate the output characteristics of the 12.5-in. OD and 5.5-in. long bed with sea-water flow rate of 11.5 lb/min (approximately half the normal flow rate). The results are presented in Figure 75.

(5) A flow test was made with a strong cationic-exchange bed with a 3-in. dia and an 8-ft length (made by connecting two 4-ft chambers in series). This unit is shown in Figure 59. The quantity of Amberlite IR-120 exchange resin used was the same as that used with the previous ion-exchange tests (bed size of 12-1/2 in. OD and 5.5-in. length). A constant flow of sea water at 23 lb/min was maintained through the bed during the test. The percentage of cationic exchange was measured as a function of time for a 9-min period (see Figure 76). The purpose of the test was to determine if a more desirable characteristic of percent ion exchange vs time could be obtained with a higher length-to-diameter ratio for bed shape. Results indicated that there was no significant improvement.

(6) Another flow test was made using the ion-exchange unit mentioned above (Figure 59) but with 50% of the sea water bypassed around the bed during the first half of the test period (see Figure 76). On the basis of the foregoing test results, it is believed that if the percentage of cationic exchange can be maintained above a minimum value of approximately 40%, the amount of solid deposits will be kept to a satisfactory level for operation of the torpedo.

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

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(7) Two additional flow tests were made in which Amberlite IR-120 exchange resin was used in the 3-in. dia, 8-ft-long chamber (see Figure 59). The results are shown in the curves of Figures 77 and 78.

(a) For the first flow test, a constant flow of natural sea water of 5.75 lb/min (25% of the total flow required for the Mk 16-6 torpedo engine) was maintained through the exchange bed, with 17.25 lb/min by-passed around the bed. The curve of Figure 77 shows that this exchange resin bed is adequate to process the 5.75 lb/min flow for at least 12 min.

(b) The second flow test was made with the flow through the exchange resin bed increased to 8.1 lb/min (35% of the sea-water diluent flow required for the Mk 16-6 torpedo engine). The curve of Figure 78 shows that the exchange resin bed should be increased slightly in size to completely process this amount of sea water for the required 9 min of the torpedo-engine operation.

i. Ten tests were conducted with special additives in the sea-water diluent. These additives were of two general categories: Chelating agents and colloidal materials. These tests (No. 27 through 36) are described and results presented in Tables 6 and 8.

Tests No. 27 and 28 were made with Quebracho, which is used with boiler feed water in some commercial applications. Tests No. 29 and 30 used a detergent, Tergitol Anionic 08, which had been investigated to some extent by USNOTS, Pasadena, for use in combustion tests with fluidized metals, hydrogen peroxide, and diluent sea water. Difficulty was experienced with the burning of hardware surrounding the primary (hot) combustion zone on Tests No. 29 and 30. This damage was caused by the poor heat-transfer characteristics of the diluent in the regenerative cooling passages as a result of the foam formed in the sea water by the Tergitol additive. Tests No. 31 and 32 were made using lignin extract and hydrazine sulfate additives, respectively. The overall results were not encouraging when additives of various types were used with the sea water. It was considered necessary to make an adequate number of tests so that most types of additive materials that might make possible the use of sea water as a diluent would be tried. With the completion of these tests, this approach to the problem was abandoned, because no promising results were obtained with the materials tested

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E. DISCUSSION OF RESULTS

1. The most satisfactory results were obtained when the sea water had been partially processed by a cationic-exchange treatment. None of the tests with additives produced results that were considered satisfactory enough to warrant further investigation of this method for using sea-water diluent.

2. It was estimated, on the basis of the data from the combustion tests conducted (see Tables 5 through 8), that 40% of the sea-water diluent would need the complete cationic-exchange treatment in order to control satisfactorily the solid deposits in an engine such as used in the Torpedo Mk 16-6. Using the curves of Figures 77 and 78, a conservative estimate of the volume of Amberlite IR-120 resin required to accomplish this task is 0.63 cu ft. Results of the tests described in Section D, above, showed that the shape of the exchange-resin bed is not important, but rather the flow distribution and the amount of the resin.

a. Assuming that 0.37 cu ft of space is needed for a sea-water diluent pump and its accessories, and that 0.63 cu ft is needed for the tank which houses the Amberlite IR-120 resin, then a total of 1.0 cu ft will be necessary for the complete sea-water diluent system. This could result in a reduction of 4.60 cu ft in the size of the Torpedo Mk 16-6 if the torpedo were redesigned to incorporate the sea-water diluent system.* The refitting of this torpedo by replacing the fresh-water tank with additional fuel and hydrogen peroxide tankage would result in an increase in range of 35% if the air flask remained the same size.

b. For torpedo engines using 90% hydrogen peroxide and diesel fuel, the gain in performance would be greater, because the diluent flow rate is materially higher when these propellants are used.

3. At the conclusion of the work described above, the contracting agency formally directed that all test work stop on this phase of the program, because experimental work conducted by another agency appeared to be giving satisfactory results; it was the desire of the contracting agency to review these other tests completely, prior to any continuation of this program so that duplication of effort would not occur. Accordingly, no additional work was conducted on this program during the contract period.

* 3.32 cu ft for the fresh-water tank, 2.28 cu ft for reduction in size of the required air flasks minus 1.0 cu ft for the sea-water diluent system.

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

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4. Because the most promising results were obtained with the cationic-exchange treated sea water, it is specifically recommended, if additional development effort is needed in order to use sea water as the diluent in H_2O_2 -hydrocarbon-fuel engines, that further work be conducted with this method. Refinements should be made to the process of bypassing part of the sea water and treating the remainder. The method should then be completely proved by incorporating the treatment process with combustion tests of the complete torpedo power plant.

VI. SUBMARINE POWER PLANT, FEASIBILITY STUDY PROGRAM

A. PURPOSE

The purpose of this phase of the work under the contract was to conduct a theoretical investigation of power-plant parameters for a small high-speed submarine using a liquid oxidant in a semiclosed cycle.

The program consisted of a series of feasibility studies regarding complete power-plant systems and various components related to these systems.

The following submarine power-plant specifications were used throughout:

1. 1900-shaft-horsepower output
2. Operation from 0 to 1000-ft depth
3. 50 duty cycles of 2 hr each
4. Operation at various power levels from 5 shp to maximum
5. Reversing capabilities
6. Independent auxiliary power
7. Highest possible performance for the power plant
8. Smallest size and weight of power-plant hardware
9. Maximum safety, operational convenience, and reliability of power-plant designs.
10. Use of liquid propellants
11. 2100-rpm counter-rotating propeller drive.

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

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B. SUMMARY OF STUDY PROGRAM

1. The detailed results of this power-plant study for a small, high-speed submarine were presented in Reference 11. (This report received the same distribution as the present report so that this work is only briefly summarized below).

2. On the basis of the investigations conducted during this program, the following general characteristics and features of a 1900 shp power-plant system represent the best design from a standpoint of performance, size and basic simplicity:

a. The propellant tanks are of Dacron and Mylar exposed to the ambient sea-water pressure.

b. The propellants used are 90% H_2O_2 , diesel fuel, and sea-water diluent.

c. The turbine wheel is of 12-in. dia with a rotative speed of 25,000 rpm and operating temperature of 1900°F.

d. A condensing system is used on the turbine exhaust with a vane-type compressor pump to discharge the mixture of water and CO_2 from the condenser to the ambient sea water.

e. Special sliding-ring variable displacement-positive displacement vane pumps are used for all propellants to simplify the power-plant control system.

f. A 5-hp combination electric motor and generator is used to provide for low-speed operation, reversing, and starting of the main power plant and auxiliary diesel engine.

g. The power-plant performance is 6.29 and 7.04 lb of expendables per shp hour for operation at the surface and at 1000-ft depth, respectively.

h. A planetary-reduction gear system is used with the turbine.

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VI Submarine Power Plant, Feasibility Study
Program, B (cont.)

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- i. The combustion chamber is of the "bluff body" type.
3. The primary advantages gained from this design with a condensing system compared to designs without a condensing system are listed below:
 - a. A high-efficiency turbine performance is obtained at depth.
 - b. Only a single decomposition and combustion-chamber assembly is required.
 - c. The combustion pressure is lower at depth and less power is required for the propellant pumps.
 - d. The flushing action is improved for the sea-water solids in the turbine exhaust.
 - e. The power-plant size is smaller (3 ft OD and 3 ft long).
4. The disadvantages in using this condensing system include a slight increase in weight, and complexity of the complete power plant with the addition of the condensing-system equipment.

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TABLE 1

NET THRUST COMPARISON - HYDRODUCT MODEL

<u>Chamber Pressure</u> <u>P_c (psig)</u>	<u>Velocity</u> <u>ft/sec</u>	<u>Net Thrust</u> <u>lb</u>	<u>Thrust Coeff.</u> <u>C_F</u>
210	68.7	125	1.11
210	88.4	112	.99
210	105.8	107	.95
210	141.0	118	1.05
210	148.5	115	1.02

* Net thrust equals the gross drag of the test unit before the steam is turned on minus the gross drag at the indicated chamber pressure.

Table 1

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TABLE 2

PERFORMANCE COMPARISON

EXTERNAL-CONDENSING HYDRODUCTOR MODELS

Model No.	Velocity ft/sec	Max P _c psig	Net Thrust* lb	Thrust Coeff. C _F	Cavity Parameter \bar{U} k
X3	68.9	230	159	1.29	.476
X3	74.4	231	168	1.36	.394
X3	86.6	207	149	1.34	.288
X3	94.0	269	161	1.11	.188
X3	101.2	198	146	1.37	.131
X3	114.2	252	119	.89	.110
X3	117.8	210	89	.79	.109
X3	128.2	220	77	.65	.097
X3	132.8	207	71	.64	.061
X4	85.6	220	140	1.19	.126
X5	87.0	186	111	1.10	.151
X6	86.8	203	122	1.12	.221
X7	66.3	225	170	1.41	.548
X7	87.8	230	165	1.34	.313
X7	109.7	226	146	1.21	.120
X7	136.2	233	147	1.18	.090
X7	150.2	214	146	1.27	.018
X8	65.4	238	139	1.09	.408
X8	87.2	225	135	1.12	.248
X8	105.8	202	128	1.10	.095
X8	136.6	175	68	.70	.037
X8	148.9	239	127	.99	.019

* Net thrust equals the gross drag of the test unit before the steam is turned on minus the gross drag at the indicated chamber pressure.

Table 2

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TABLE 3

TEST DATA - LAKE PEND OREILLE RANGE

	<u>Test No. 1</u>	<u>Test No. 2</u>	<u>Test No. 3</u>	<u>Test No. 4</u>	<u>Test No. 5</u>	<u>Test No. 6</u>
Missile Type	XHDR	XHDR	HD	XHDR	XHDR	XHDR
Missile No.	1	5	6	2	3	4
Water-Flow-Limiting Valve	Yes	No	No	Yes	Yes	Yes
Depth of Launcher Muzzle (ft)	32	40	40	40	40	40
Missile Weight (lb)	56.7	56.8	51.1	56.3	56.3	54.6
Total Launching Weight (lb) (Booster and Missile)	153.4	153.5	152.1	138.0	131.0	123.8
No. of Arresting Lines on Booster	3	3	3	3	1	0
Shape of Afterbody	Regular	Regular	None	Regular	Regular	Short
Launching Velocity* (ft/sec)	172	169	**	181	194	214
Ave. Vel. (ft/sec) 34 - 88 ft	173***	168	-	175	183	196
Ave. Vel. (ft/sec) 88 - 118 ft	166	172	-	179	192	187
Ave. Vel. (ft/sec) 118 - 148 ft		156	90	172	188	178
Ave. Vel. (ft/sec) 148 - 173 ft	131	145	96	165	182	178
Ave. Vel. (ft/sec) 178 - 208 ft		129	-	148	161	173
Ave. Vel. (ft/sec) 208 - 254 ft		120	53	-		
Ave. Vel. (ft/sec) 254 - 300 ft	98	112	-	-	127	143
Terminal Vel. (ft/sec)	56	-	29	53	64	45

* Highest Ave. Vel. for minimum of 3-ft travel in launcher.

** Booster did not ignite properly.

*** 58 to 88 ft.

Table 3

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TABLE 1

COMPOSITION OF SEA-WATER DILUENT SAMPLES

<u>Constituent</u>	<u>Synthetic Sea Water (Diluent E) % by wt</u>	<u>Harbor Sea Water (Diluent F) % by wt</u>	<u>Offshore Sea Water (Diluent G) % by wt</u>	<u>Harbor-Entrance Sea Water (Diluent H) % by wt</u>
H ₂ O	96.57	96.52	96.56	96.41
Salts	3.43	3.48	3.44	3.59
Sodium	27.0	25.0	29.58	33.0
Magnesium	4.1	4.9	3.5	3.4
Calcium	3.8	4.2	4.1	2.7
Aluminum	0.0028	0.0038	0.001	0.0012
Silicon	0.039	0.063	0.032	0.049
Potassium	3.2	3.1	3.1	2.2
Strontium	0.11	0.063	0.052	not reported
Chromium	trace	0.00047	0.017	0.0073
Iron	0.033	0.016	0.12	0.013
Boron	0.080	0.072	0.036	0.048
Copper	0.0024	0.00048	0.0011	0.00076
Nickel	not reported	not reported	0.0038	0.0016
Manganese	not reported	not reported	0.0014	0.00082
Titanium	not reported	not reported	nil	0.0060

Table 1

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TABLE 5

DESCRIPTION OF TESTS, OUR SEA-WATER-DILUENT PROGRAMS 6/6/56 to 12/5/56							Reports
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	Deaerated Amount of Diluent %	
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	1330	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	2540+	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	F - 20.0	NaOH	1490	None	Results comparable to Run No. 9.
12	A - 9.7	C - 41.0	F - 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 Run 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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Report No. 1582

TABLE 6

DESCRIPTION OF TESTS, ONR SEA-WATER DILUENT PROGRAM
6 December 1956 to 5 December 1957

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 Temp °F	Remarks ⁴
17	A-8.45	C-40.0	G-23.4	None	1550	Reference run. Deposits smaller and more dense than with previous diluents.
18	A-	C-	G-	None	2100	Stoichiometric mixture ratio desired. Mixture ratio control failed. Invalid as reference.
19	B-4.27	D-35.1	G-32.8	None	1950	Reference run. Deposits smaller and more dense than lower temp, 70% H ₂ O ₂ -alcohol reference runs.
20	B-4.35	D-39.0	G-35.0	None	1965	Diluent water through exchange bed 6 in. dia x 6 in. No improvement over reference run No. 19.
21	A-9.73	C-43.0	G-20.4	None	1530	Diluent water through exchange bed 12.5 in. dia x 2 in. Slight improvement over reference run No. 17.
22	A-10.3	C-45.4	G-22.5	None	1400	Diluent water through exchange bed 12.5 in. dia x 5.5 in. Significant reduction in deposits from Runs 17 and 21.

Sheet 1 of 3
Table

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Report No. 1582

TABLE 6 (cont.)

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 Temp °F	Remarks ⁴
23	B-4.85	D-34.8	G-34.9	None	1850	Diluent water through exchange bed 12.5 in. dia x 5.5 in. Significant reduction in deposits from those of Runs 19 and 20.
24	A-9.4	C-32.6	G-12.3	None	1350	Diluent water through exchange bed 12.5 in. dia x 5.5 in. Run time = 6 min. Propellant flow rate control failed. Reliable comparisons could not be made.
25	A-10.3	C-41.2	H-23.8	None	1275	Reference run. Hard, light weight crystalline deposits similar to original reference run with synthetic sea water.
26	A-10.1	C-44.7	H-25.7	None	1430	Diluent water through exchange bed 12.5 in. dia x 5.5 in. Run time = 7.5 min. Insufficient ion exchange bed capacity.
27	B-4.23	D-36.3	H-32.8	Quebracho	1920	No apparent improvement.
28	B-4.43	D-35.5	H-29.3	Quebracho	1950	No apparent improvement.
29	A-10.1	C-42.7	H-27.4	Tergitol Anionic 08	1400	No overall improvement.

Sheet 2 of 3
Table

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TABLE 6 (cont.)

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 Temp °C °F	Remarks ⁴
30	B-4.42	D-33.3	H-33.4	Tergitol Anionic 08	1850	No improvement.
31	A-8.32	C-43.2	H-29.0	Lignin Extract	1575	No improvement.
32	A-8.2	C-45.4	H-26.8	Hydrazine Sulfate	1650	No improvement.
33	A-7.9	C-43.3	H-23.3	Bentonite	1575	No improvement.
34	A-8.5	C-45.0	H-23.9	Versene Beads	1550	No improvement.
35	A-8.4	C-45.2	H-25.4	Molasses	1500	No improvement.
36	A-8.2	C-44.6	H-24.7	Bentonite	1610	No improvement.

-
- NOTES: (1) Fuel "A" is 92.5% ethyl alcohol
Fuel "B" is diesel oil.
- (2) Oxidizer "C" is 70% E concentrated hydrogen peroxide.
Oxidizer "D" is 90% concentrated hydrogen peroxide.
- (3) Diluent "G" is natural sea water obtained two miles offshore from Seal Beach, California (also see Table 3).
Diluent "H" is natural sea water obtained at the harbor entrance to the U.S. Naval Ammunition and Net Depot, Seal Beach, California (also see Table 3).
- (4) All runs were of 2-min duration unless otherwise noted.

Sheet 3 of 3
Table

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Report No. 1542

TABLE 1

TEST DATA, ONR SEA-WATER DILUENT PROGRAM

6 June 1956 to 5 December 1956

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) 1
			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 synthetic sea water and 63.2% untreated synthetic sea water	1.09	0.086	0.043	35:1
3	50% decationized synthetic 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)

Sheet 1 of 2
Table

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Report No. 1522

TABLE 7 (cont.)

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	
14	Offshore sea water, 90% H ₂ O, and diesel fuel	1.542	0.092	0.026	17:1
16	Offshore sea water, 70% E H ₂ O, 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 - 76 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.

Sheet 2 of 2
Table 7

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Report No. 1592

TABLE C

TEST DATA, ONR SEA-WATER DILUENT PROGRAM

6 December 1956 to 5 December 1957

Run No.	Description (1)	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, (2) lb
			Combustion Chamber, lb	Exhaust System, (2) lb	
17	70% E H ₂ O ₂ , ethyl alcohol, sea water	1.61	0.15	0.044	11
18	70% E H ₂ O ₂ , ethyl alcohol, sea water		Data not valid		
19	90% H ₂ O ₂ , diesel fuel, sea water (Reference run)	2.26	0.065	0.072	10
20	90% H ₂ O ₂ , diesel fuel, sea water. Diluent water through 6 in. dia x 6 in. bed of strong cationic exchange resin	2.41	0.054	0.10	22
21	70% E H ₂ O ₂ , ethyl alcohol, sea water. Diluent water through 12.5 in. dia x 2 in. bed of strong cationic exchange resin	1.40	0.065	0.044	14
22	70% E H ₂ O ₂ , ethyl alcohol, sea water. Diluent water through 12.5 in. dia x 5.5 in. bed of strong cationic exchange resin	1.54	0.004	0.028	

NOTES: (1) All runs were of 2-min duration unless otherwise noted.
 (2) Water-soluble solids only.

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Report No. 1582

TABLE 8 (cont.)

Run No.	Description (1)	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, (2) 1
			Combustion Chamber, lb	Exhaust System, (2) lb	
23	90% H ₂ O ₂ , diesel fuel, sea water. Diluent water through 12.5 in. dia x 5.5 in. bed of strong cationic exchange resin	2.40	0.010	0.0056	
24	70% E H ₂ O ₂ , ethyl alcohol, sea water. Diluent water through 12.5 in. dia x 5.5 in. bed of strong cationic exchange resin (6-min run)	0.845 (av)	0.025 (av)	0.055 (av)	
25	70% E H ₂ O ₂ , ethyl alcohol, sea water (Reference run)	1.65	0.32	0.18	(3)
26	70% E H ₂ O ₂ , ethyl alcohol, sea water. Diluent water through 12.5 in. dia x 5.5 in. bed of strong cationic exchange resin (7.5 min run)	1.76 (av)	0.115 (av)	0.27 (av)	46
27	90% H ₂ O ₂ , diesel fuel, sea water. 25 ppm Quebracho added to diluent	2.26	0.15	0.11	14
28	90% H ₂ O ₂ , diesel fuel, sea water. 1150 ppm Quebracho added to diluent	2.02	0.17	0.056	9
29	70% E H ₂ O ₂ , ethyl alcohol, sea water. 5.5% Tergitol Anionic 08 added to diluent	1.89	0.082	0.339	11

NOTE: (1) All runs were of 2-min duration unless otherwise noted.
 (2) Water-soluble solids only.
 (3) Calcium determination not made because of failure of analyzing equipment.

Page 2 of 3
Table

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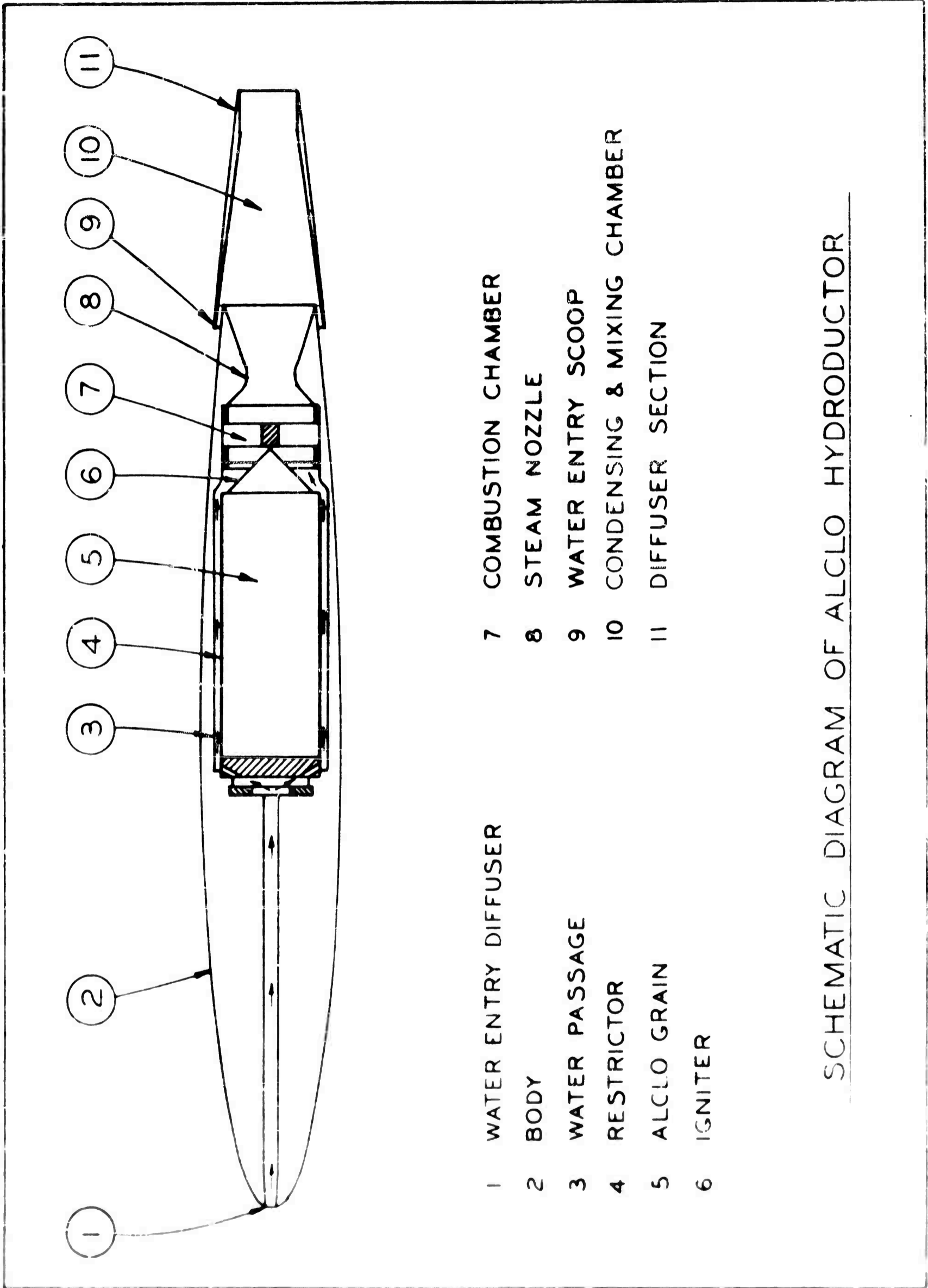
CONFIDENTIAL

Report No. 1582

TABLE 8 (cont.)

Run No.	Description (1)	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, (2) 1'
			Combustion Chamber, lb	Exhaust System, (2) lb	
30	90% H ₂ O ₂ , diesel fuel, sea water. 5.3% Tergitol Anionic O8 added to diluent	2.30	0.17	0.18	25
31	70% E H ₂ O ₂ , ethyl alcohol, sea water. 0.116% Maracell E (lignin extract) added to diluent	2.00	0.19	0.26	22
32	70% E H ₂ O ₂ , ethyl alcohol, sea water. 0.1% hydrazine sulfate added to diluent	1.85	0.27	0.21	19
33	70% E H ₂ O ₂ , ethyl alcohol, sea water with 0.06% Bentonite added	1.615	0.21	0.21	35
34	70% E H ₂ O ₂ , ethyl alcohol, sea water with 3.5% Versene beads added	3.27	0.14	0.23	200
35	70% E H ₂ O ₂ , ethyl alcohol, sea water with 0.1% molasses added	1.725	0.22	0.26	20
36	70% E H ₂ O ₂ , ethyl alcohol, sea water with 0.33% Bentonite added	1.71	0.19	0.16	38

NOTE: (1) All runs were of 2-min duration unless otherwise noted.
 (2) Water-soluble solids only.



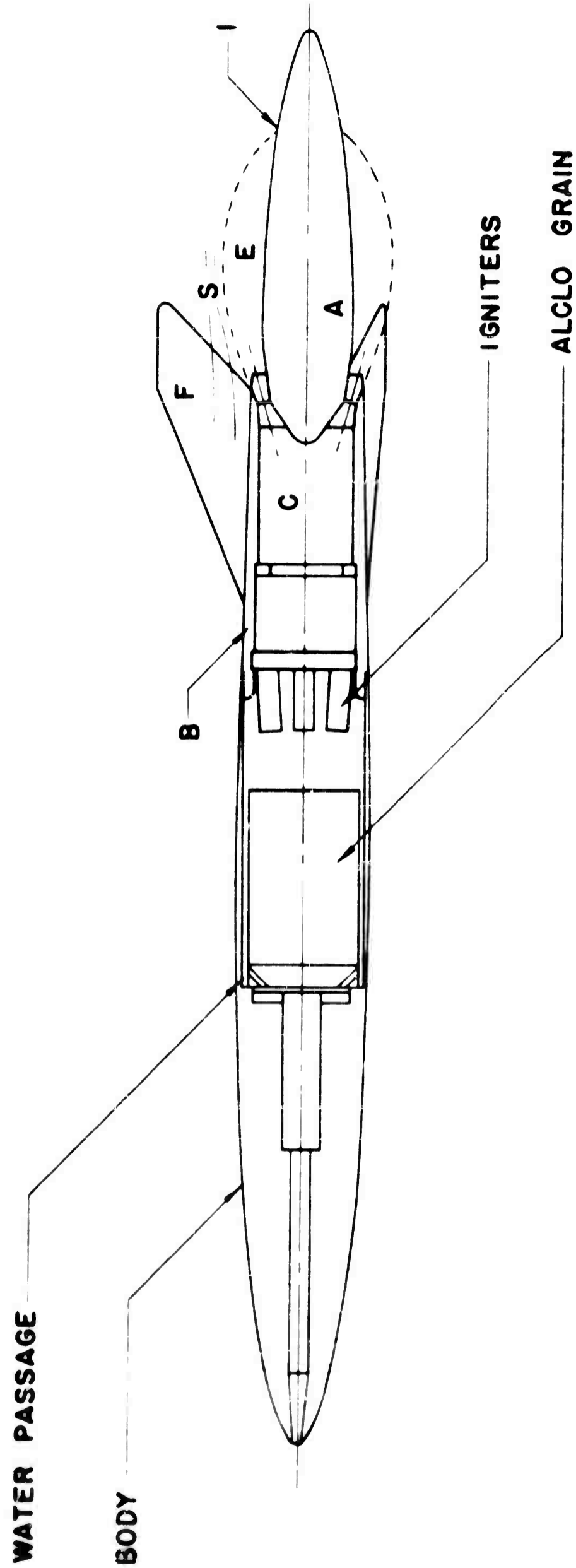
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|---|----------------------|----|-----------------------------|
| 1 | WATER ENTRY DIFFUSER | 7 | COMBUSTION CHAMBER |
| 2 | BODY | 8 | STEAM NOZZLE |
| 3 | WATER PASSAGE | 9 | WATER ENTRY SCOOP |
| 4 | RESTRICTOR | 10 | CONDENSING & MIXING CHAMBER |
| 5 | ALCLO GRAIN | 11 | DIFFUSER SECTION |
| 6 | IGNITER | | |

SCHEMATIC DIAGRAM OF ALCLO HYDRODUCTOR

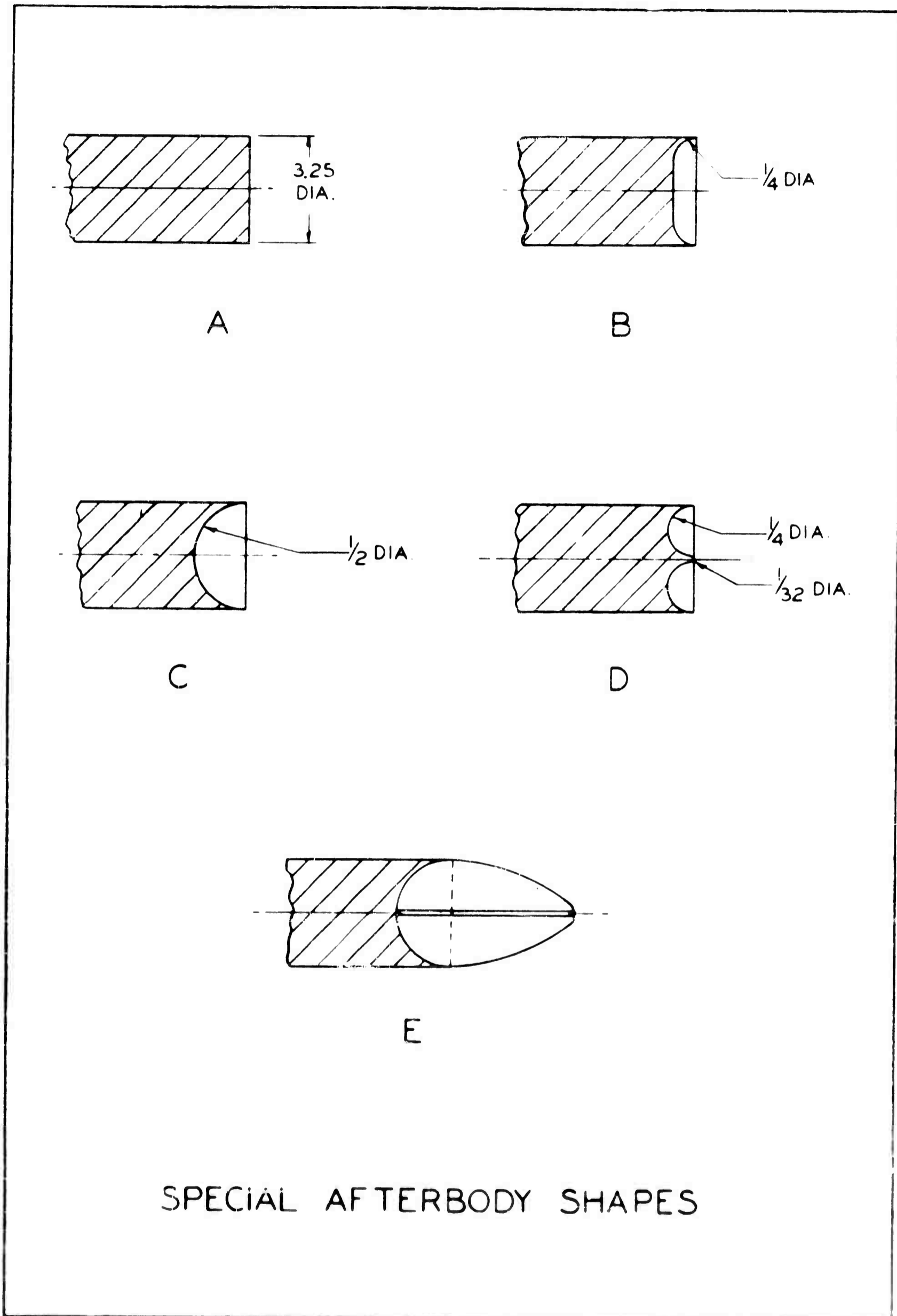


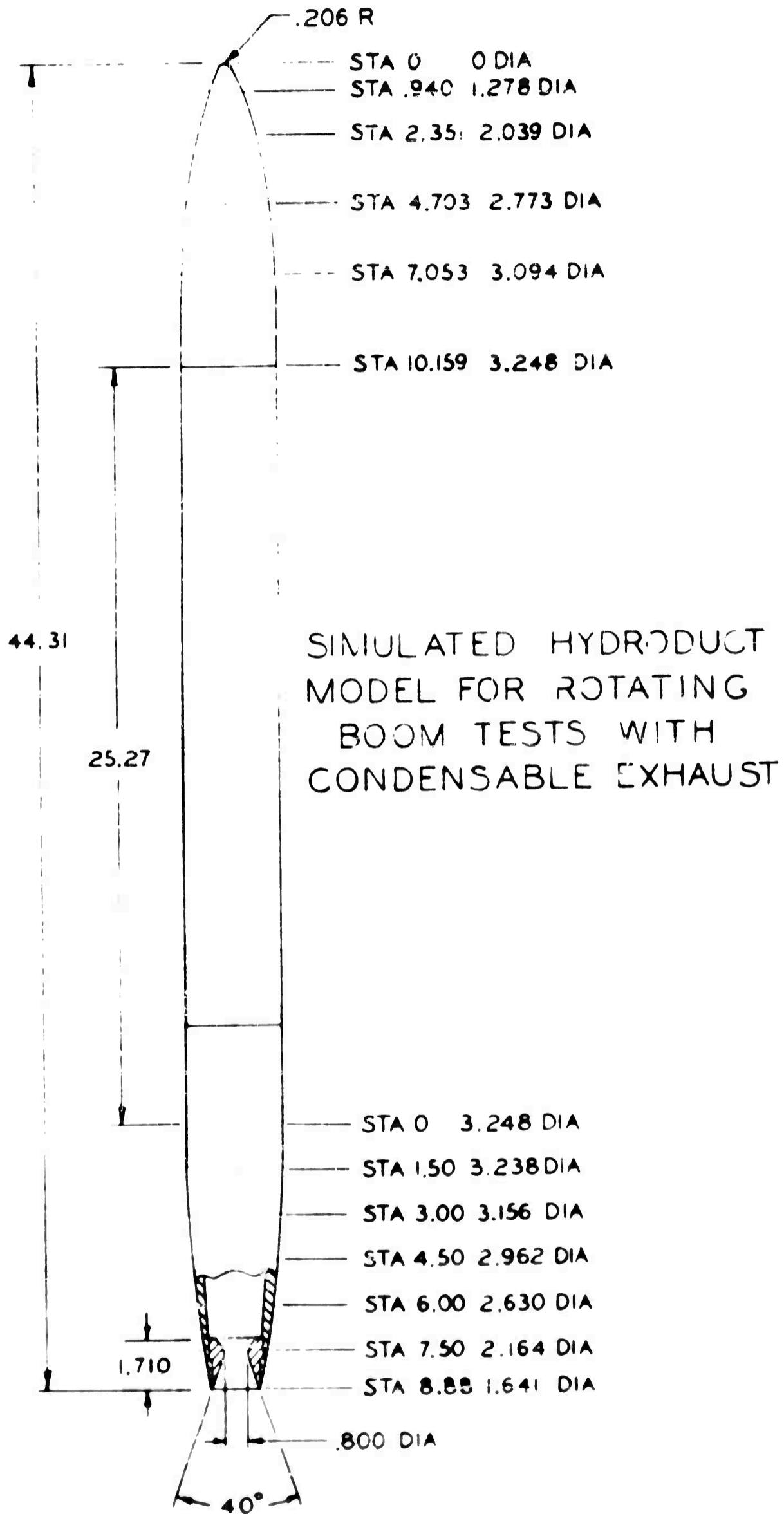
Hydroductor No. 1

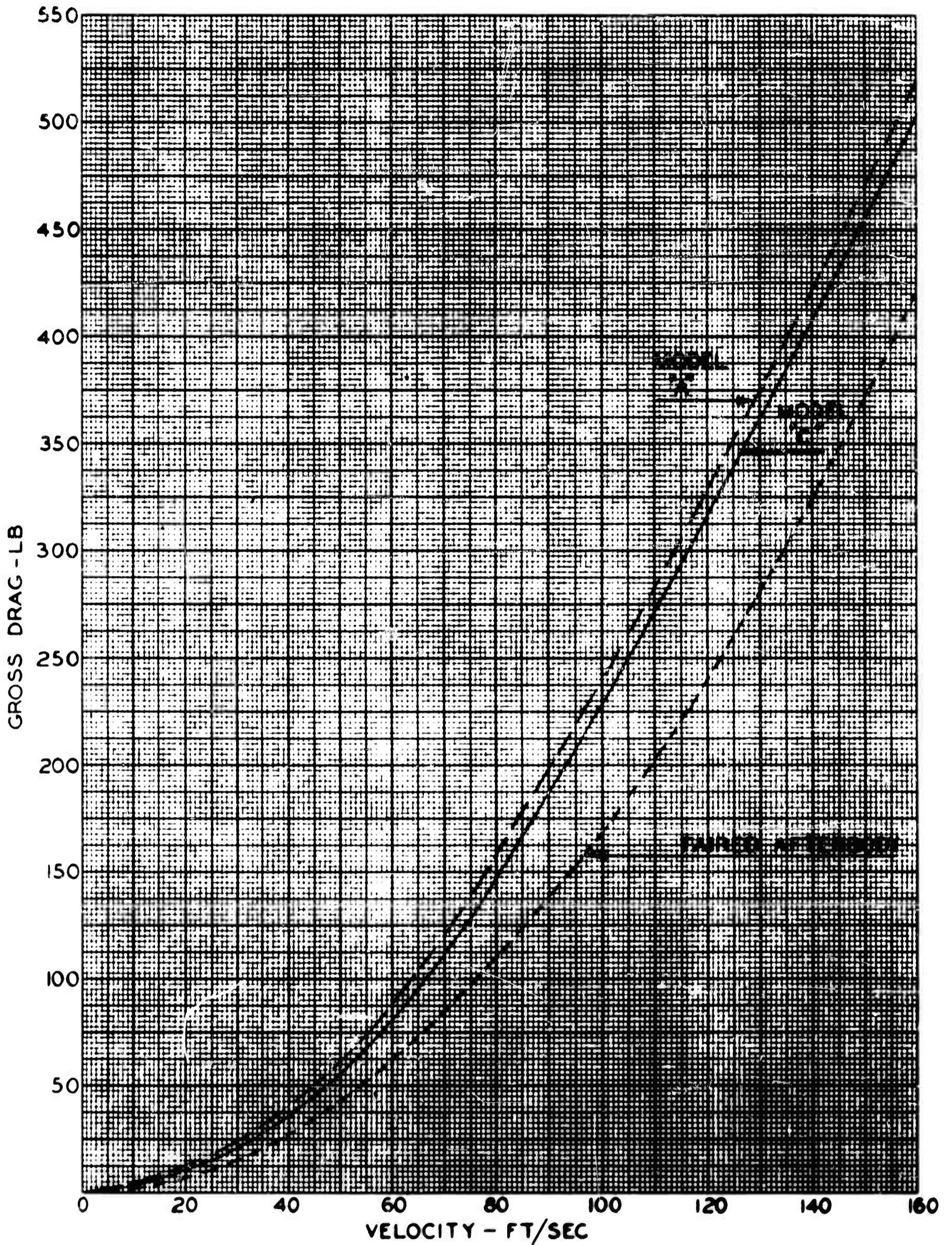
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SCHEMATIC DIAGRAM OF ALCLO EXTERNAL-CONDENSING HYDRODUCTOR

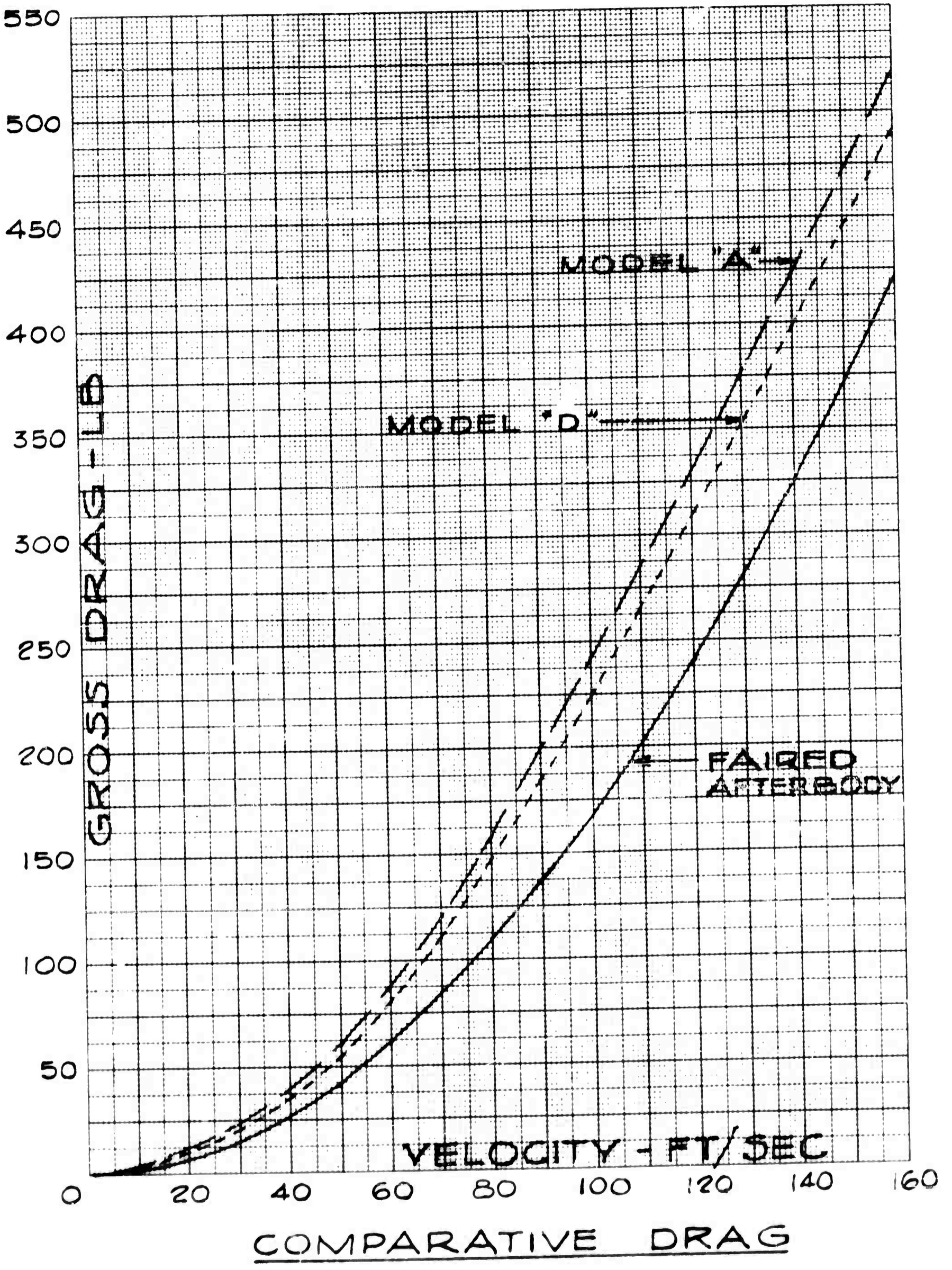




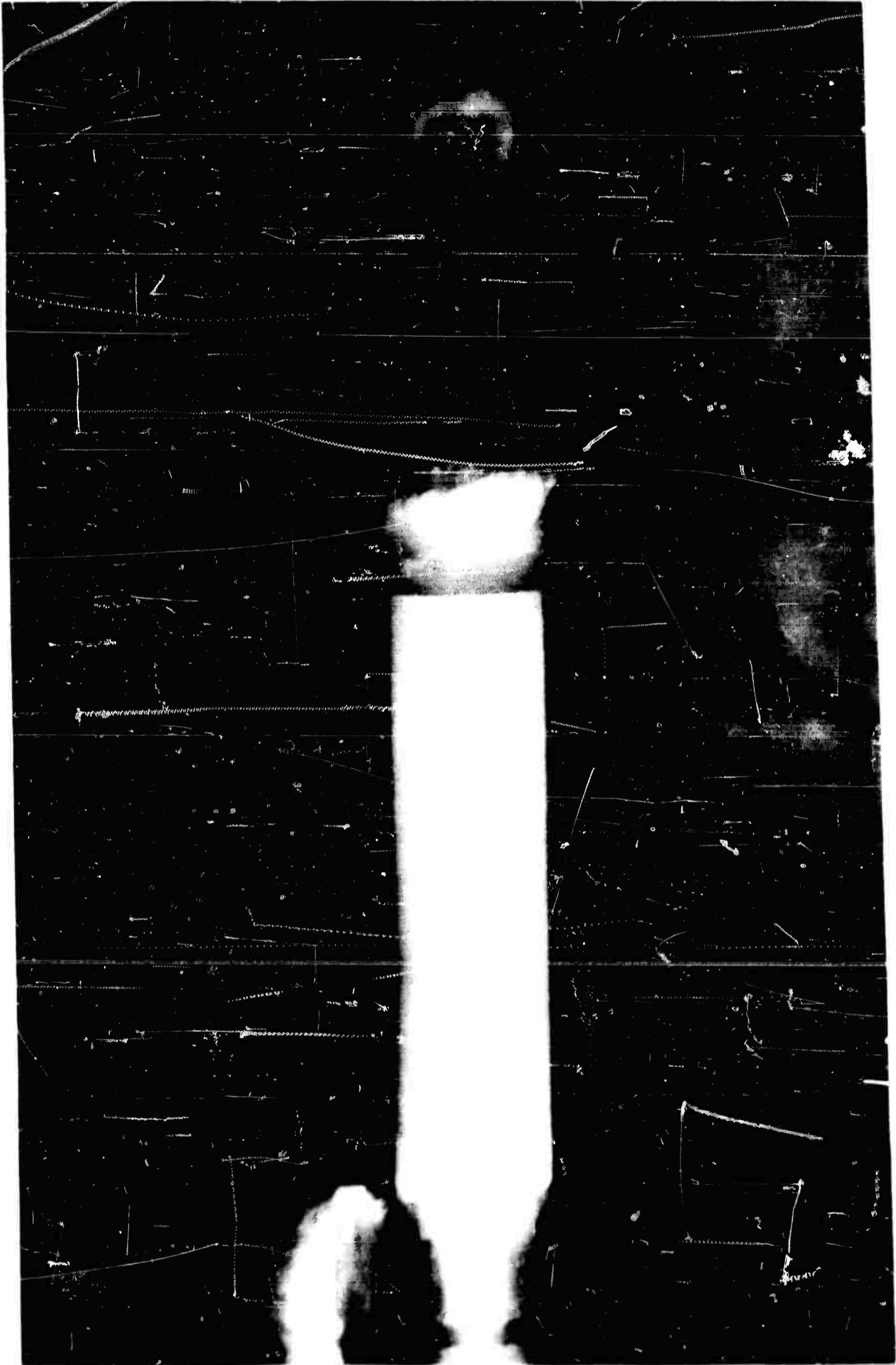


COMPARATIVE DRAG

VEC. 4686



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Microflash Photograph - Model "A", Velocity = 95.3 ft/sec

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Figure 2



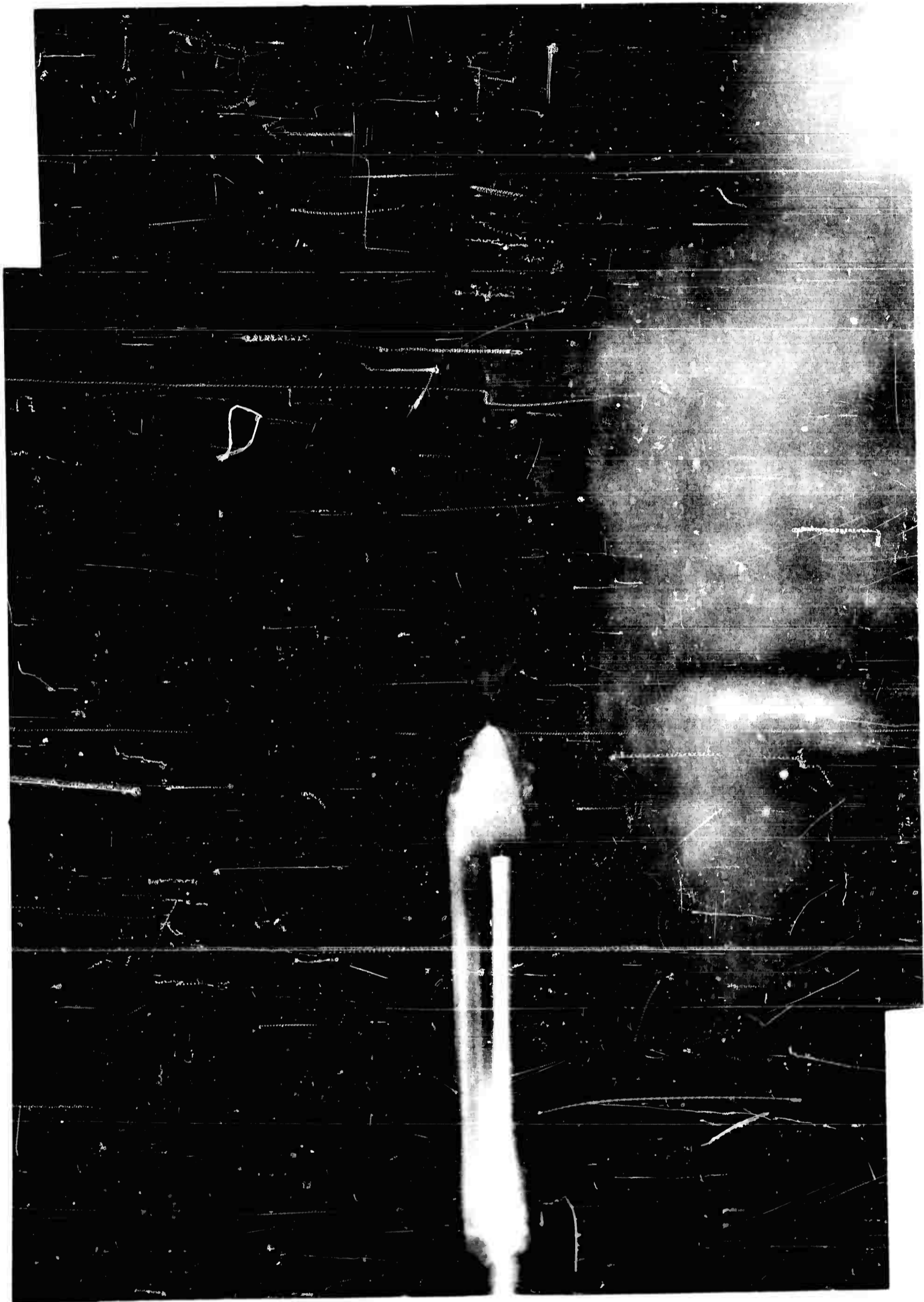
Microflash Photograph - Model "C", Velocity = 94.0 ft/sec

1256-0381



Microflash Photograph - Model "D", Velocity = 91.8 ft/sec

157-0035

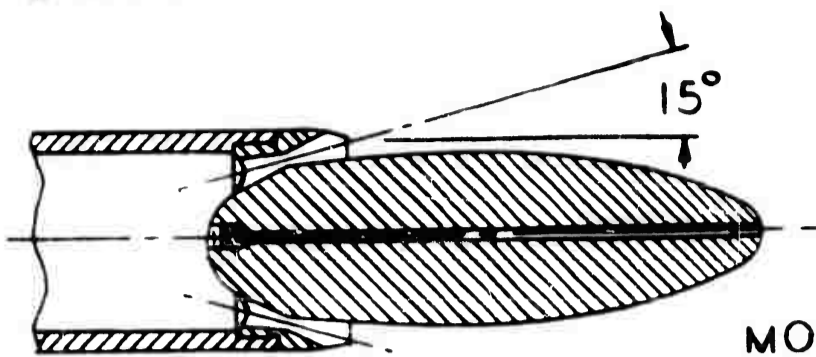


Microflash Photograph - Model "E", Velocity = 92 ft/sec

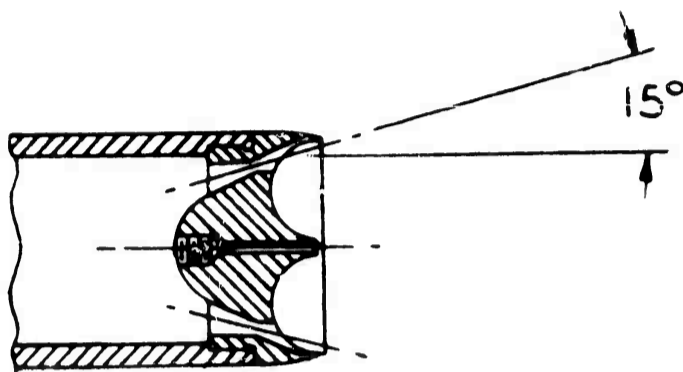
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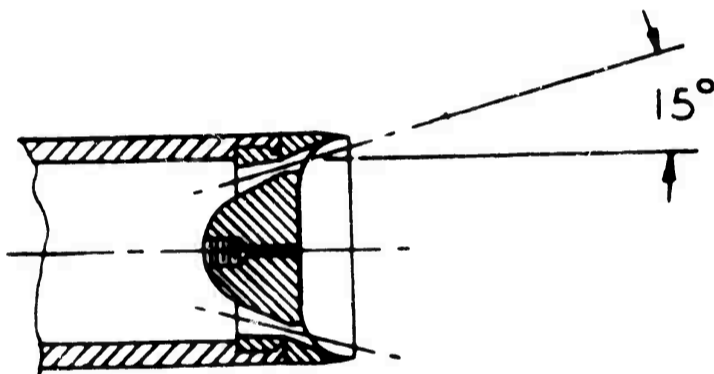
Report No. 1532



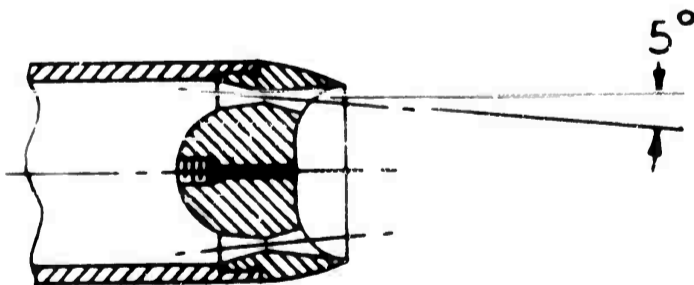
MODEL X-3



MODEL X-4



MODEL X-5



MODEL X-6

UFC - 4760 4-25-57 RMV EH

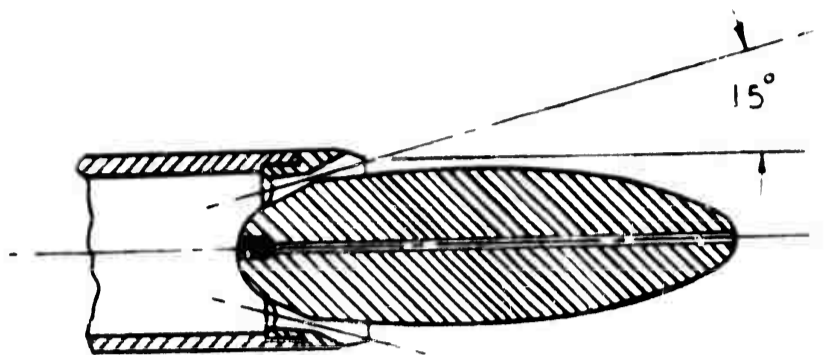
SCHEMATIC DIAGRAMS

EXTERNAL-CONDENSING
HYDRODUCTOR MODELS

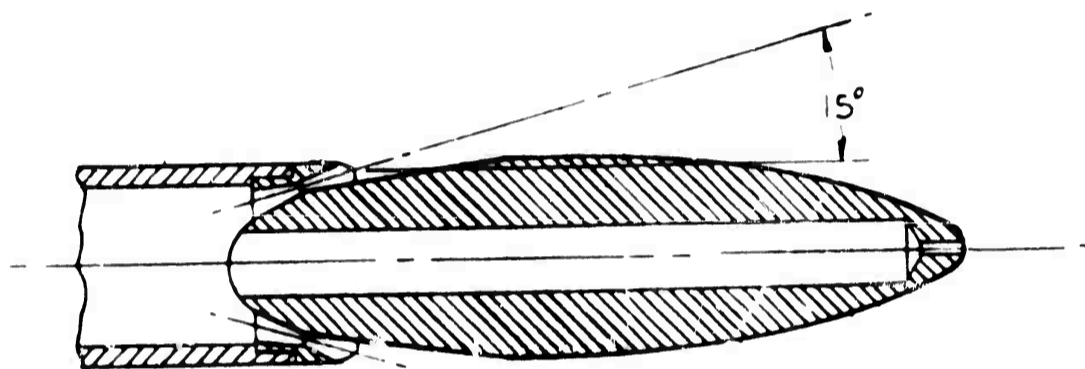
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Figure 12

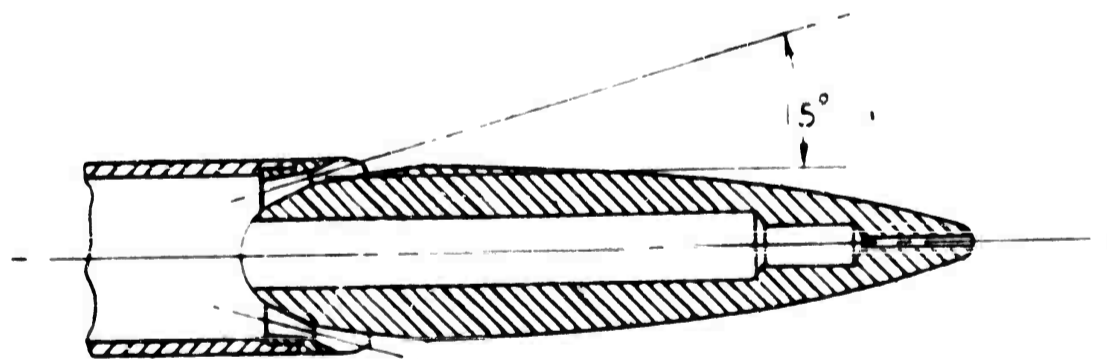
E.S./R.V. 8-20-57 VEC 4845



MODEL X-3



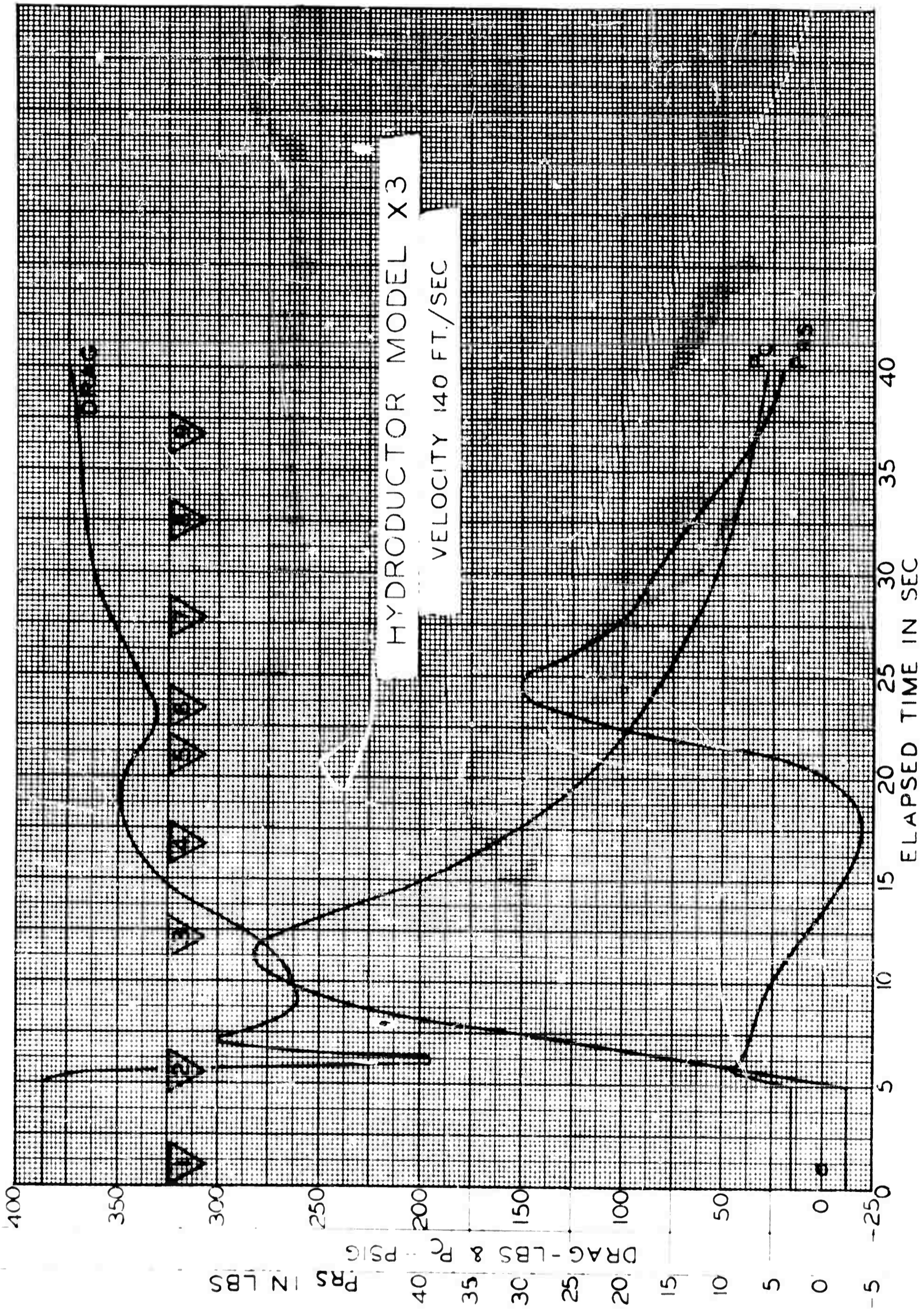
MODEL X-8



MODEL X-7

SCHEMATIC DIAGRAMS

EXTERNAL - CONDENSING HYDRODUCTOR
MODELS



Performance Curve - Model X3 Hydroductor



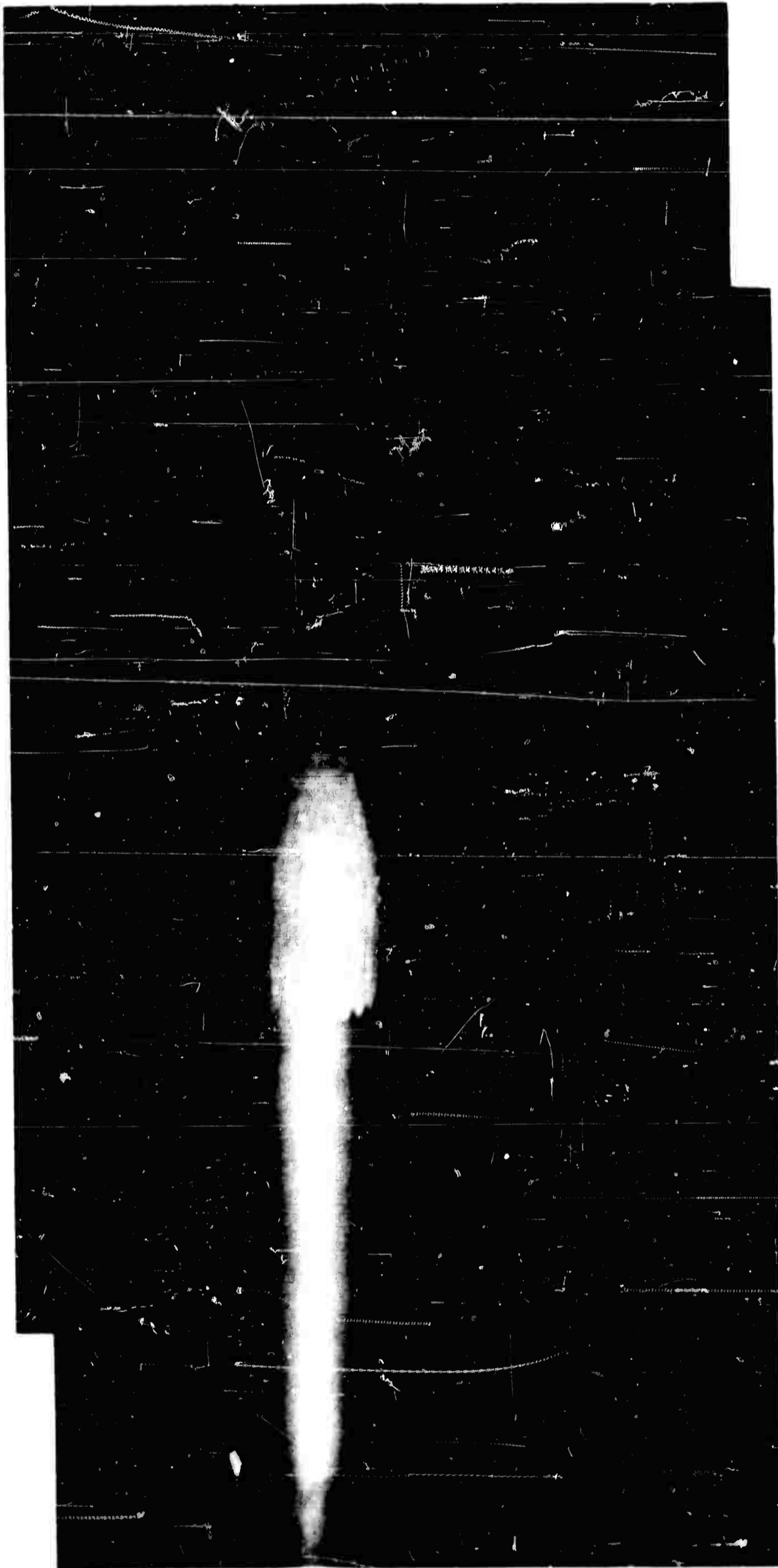
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157-605



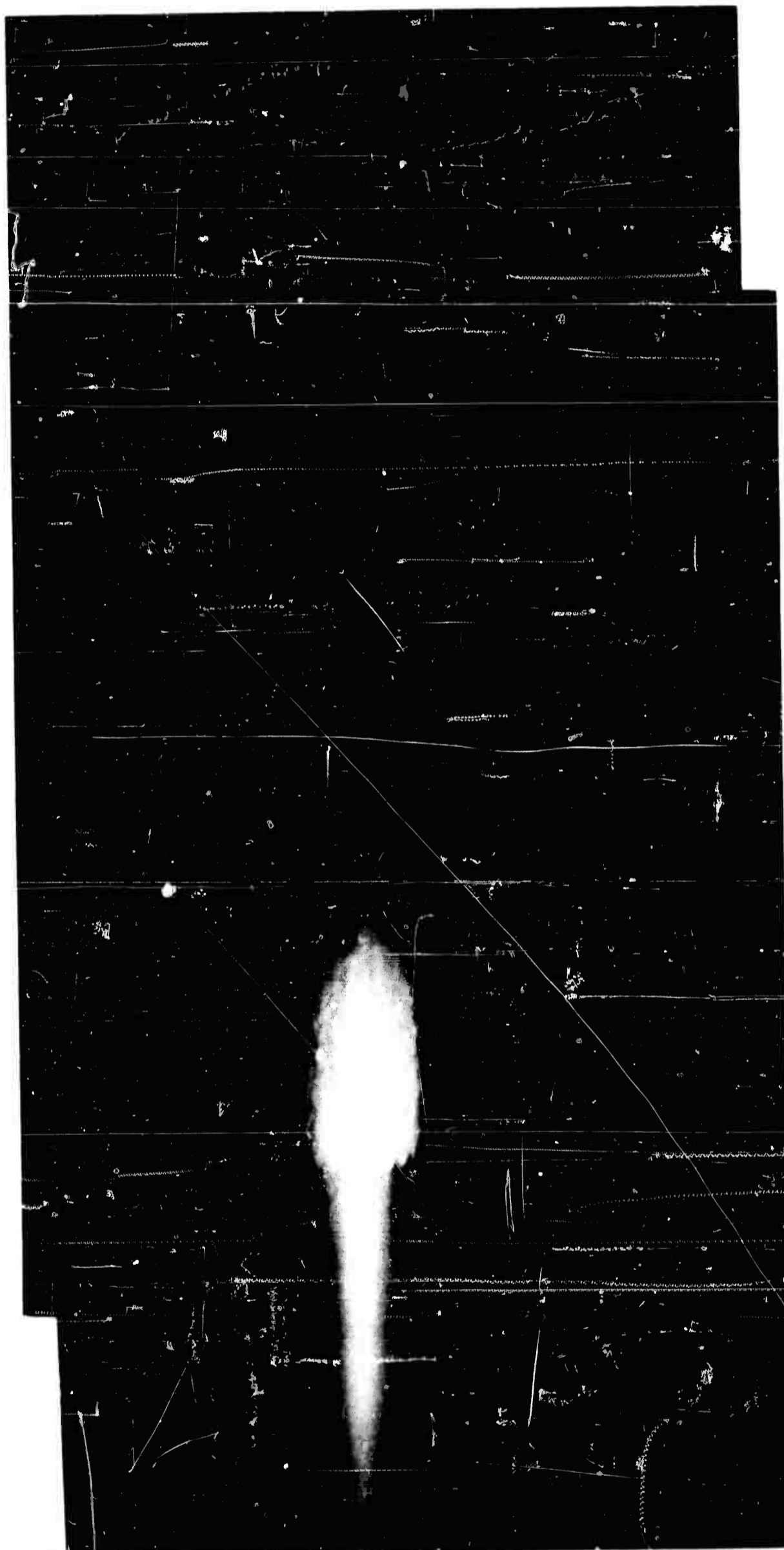
Microflash Photograph No. 3 - Hydroductor Model X3

157-607



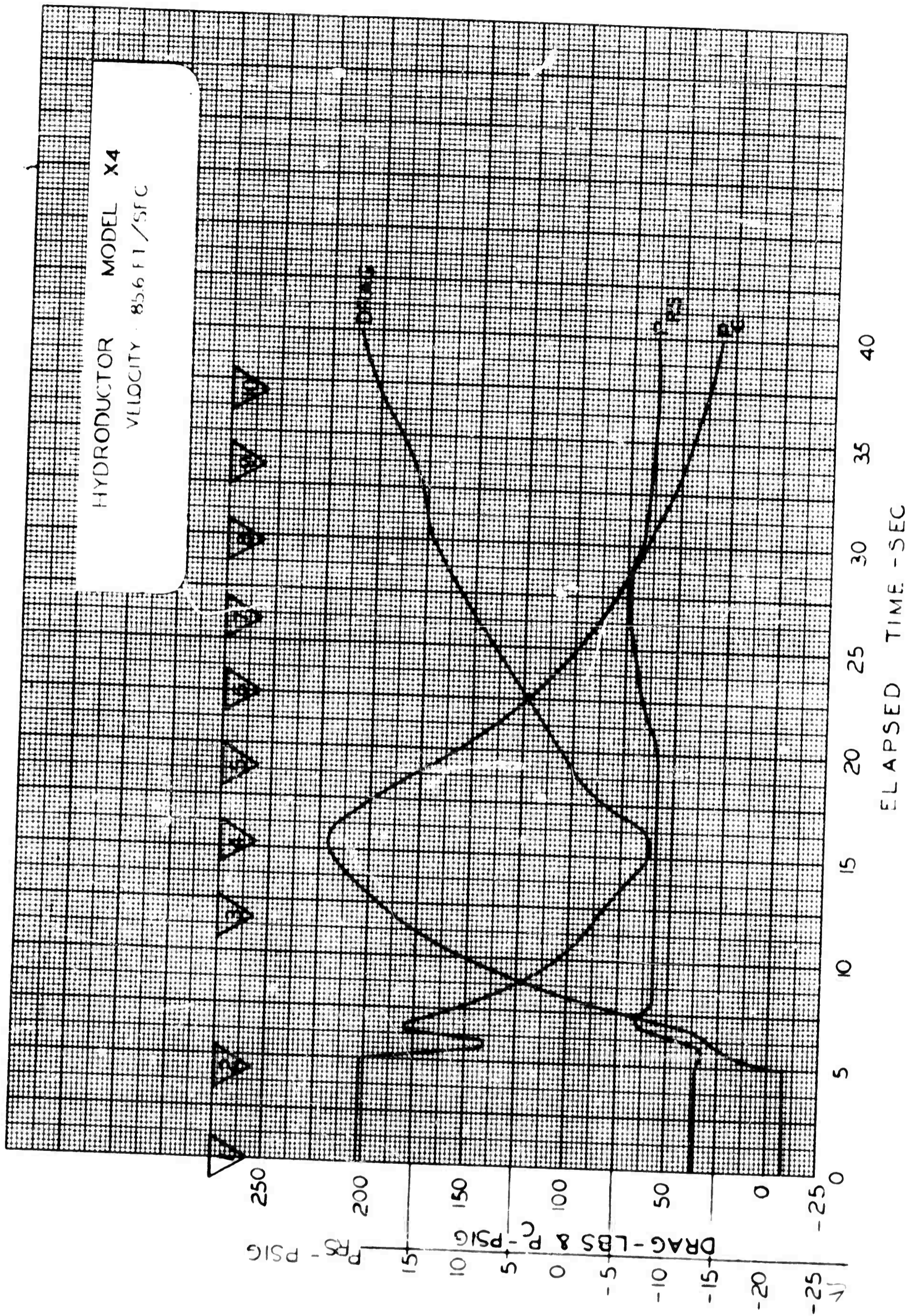
Microflash Photograph No. 5 - Hydroductor Model X3

157-609



Microflash Photograph No. 6 - Hydroductor Model X3

157-610



Performance Curve - Hydroductor Model X4 - Velocity 85.6 ft/sec



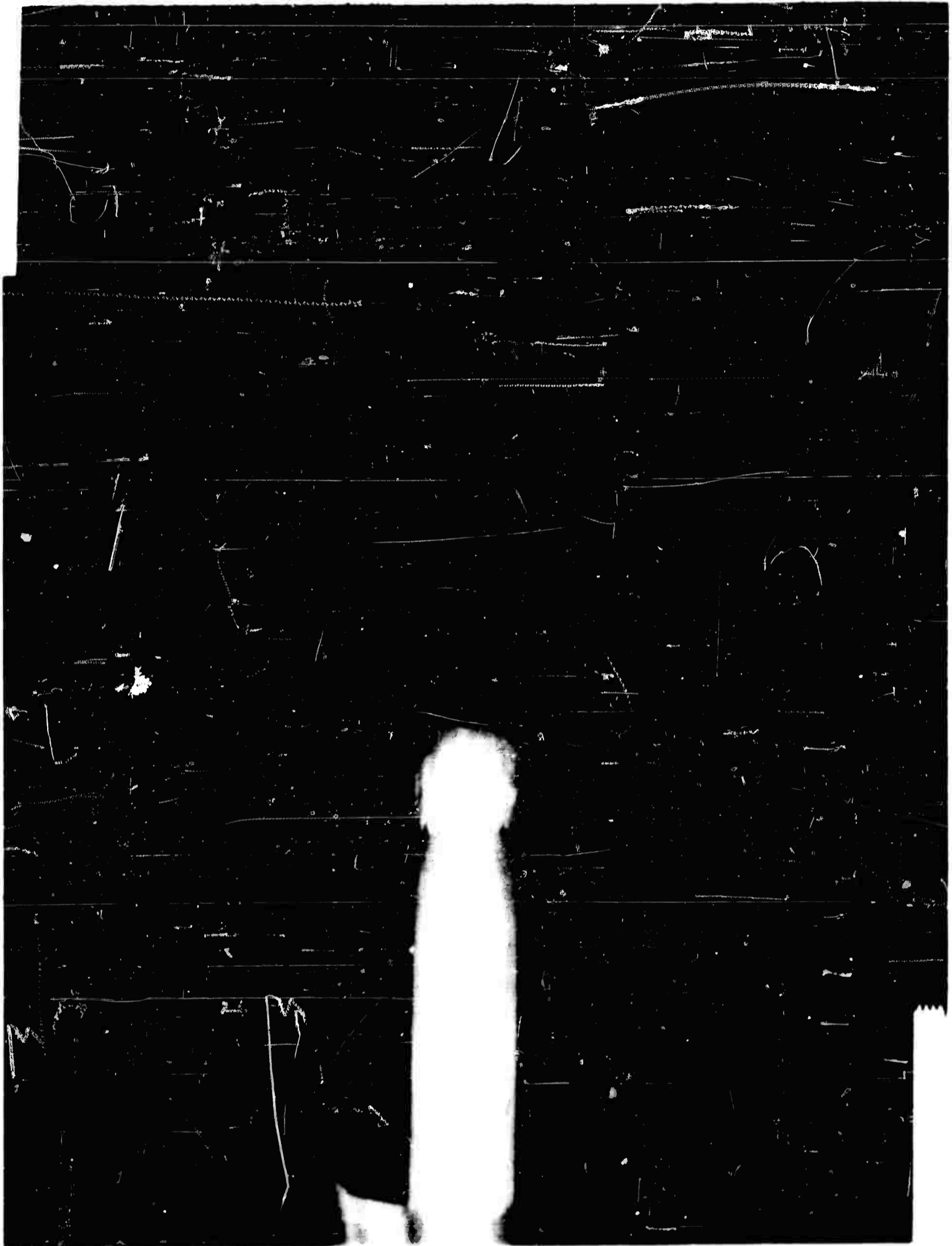
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Microflash Photograph No. 1 - Hydroductor Model Xi



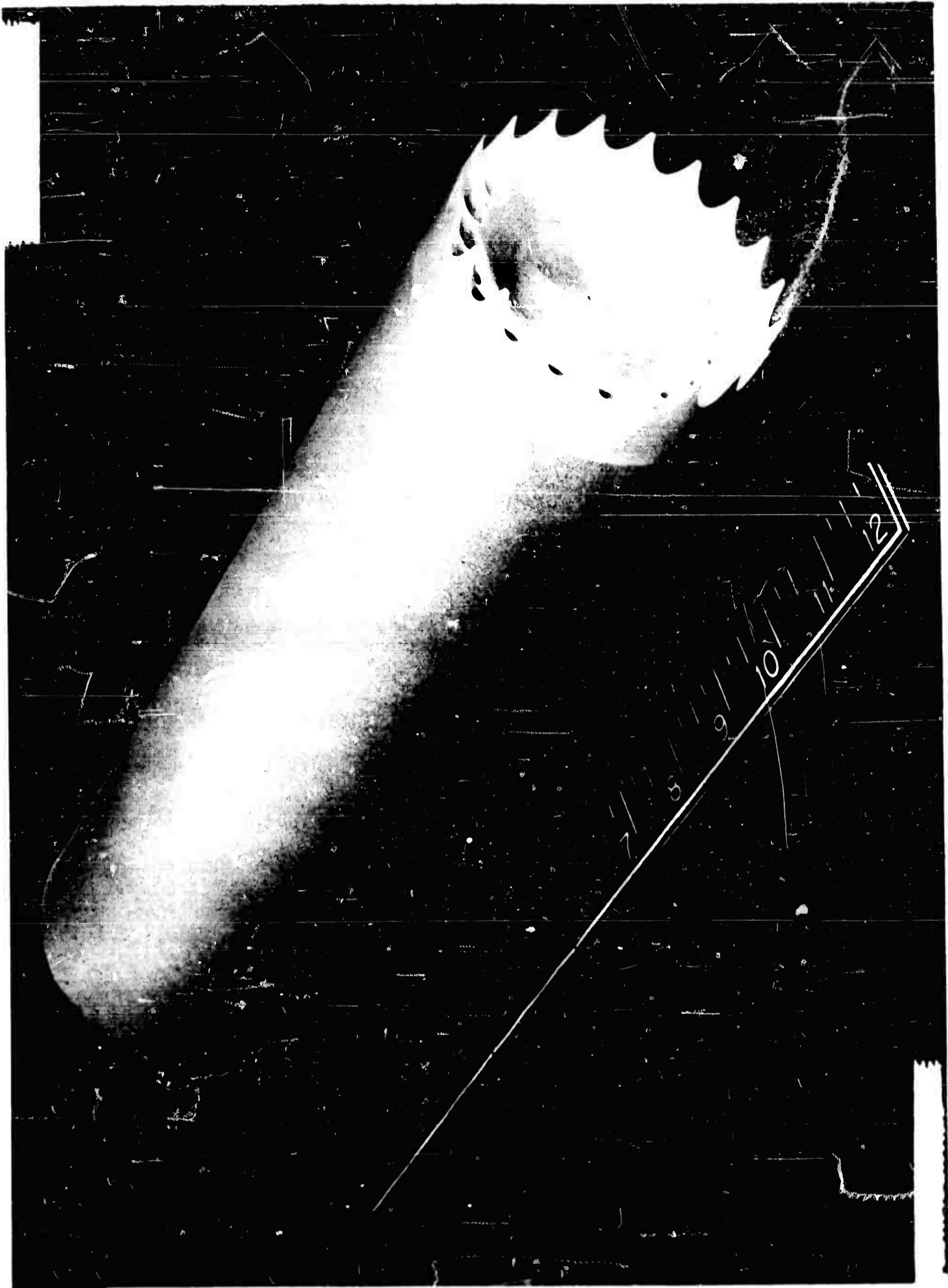
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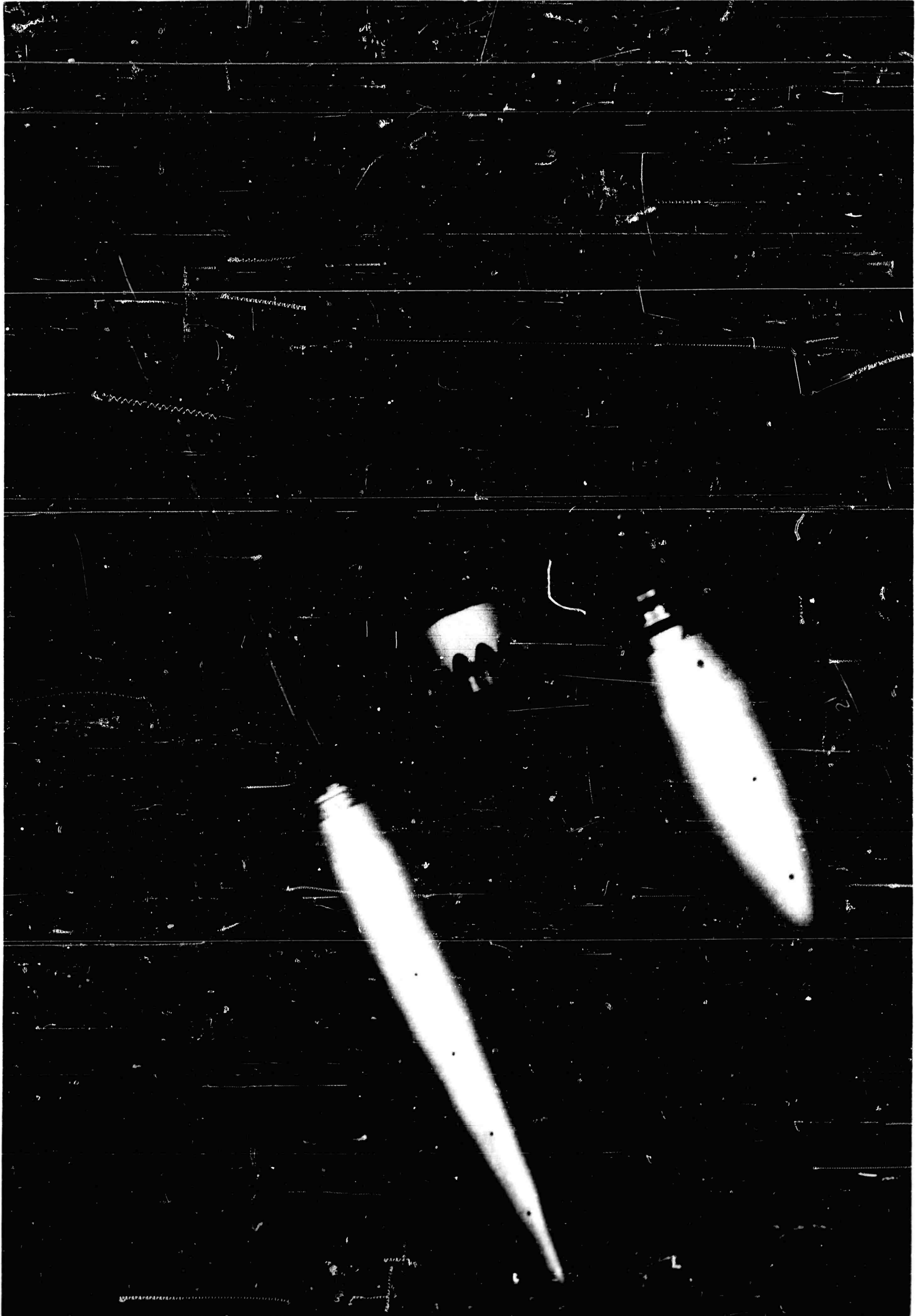
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Microflash Photograph No. 7 - Hydroductor Model X4



External-Condensing Hydroductor Model X5

257-1137



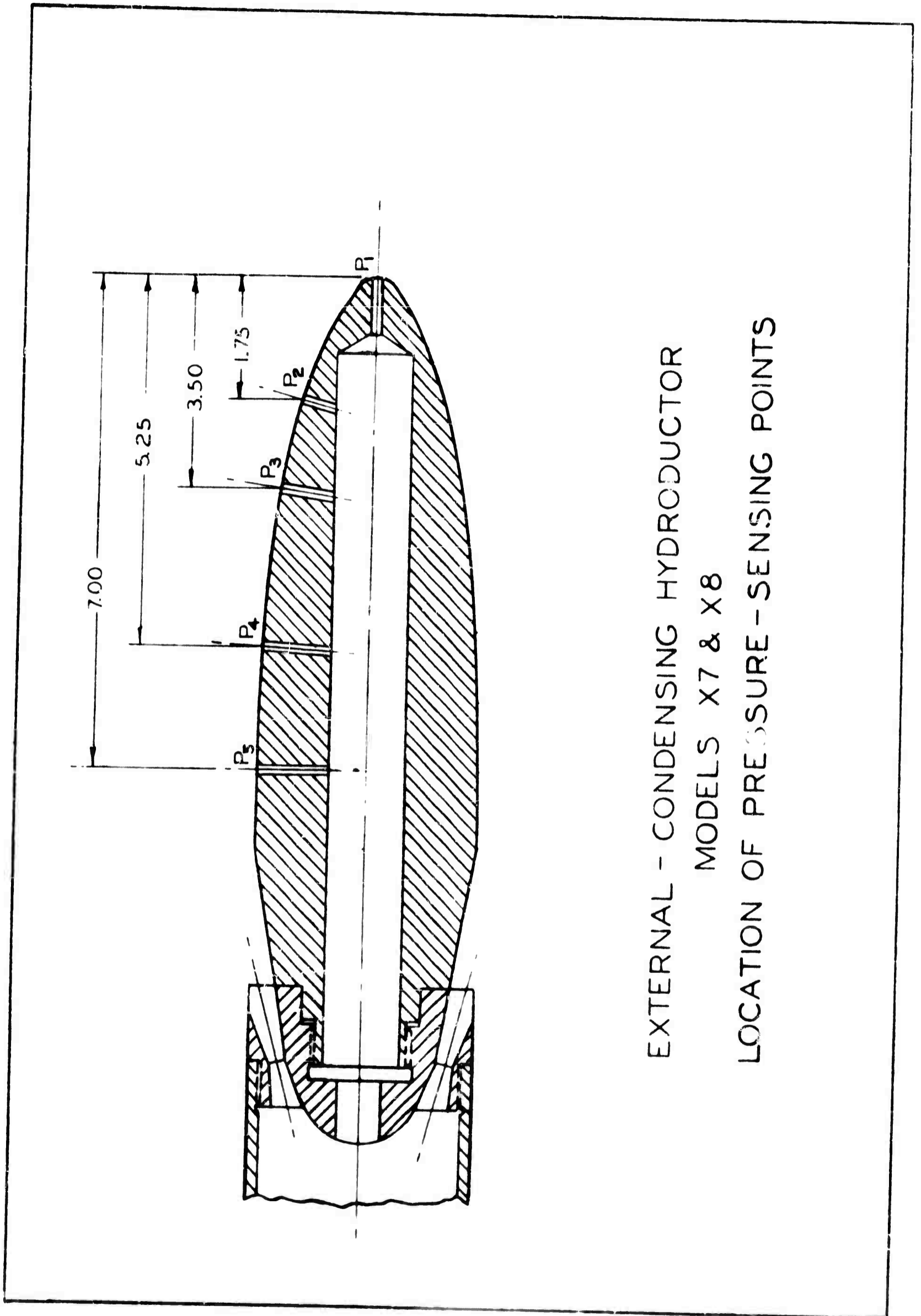
Model X7 and Model X3 Hydroductor Afterbodies and Common Nozzle Block

757-229



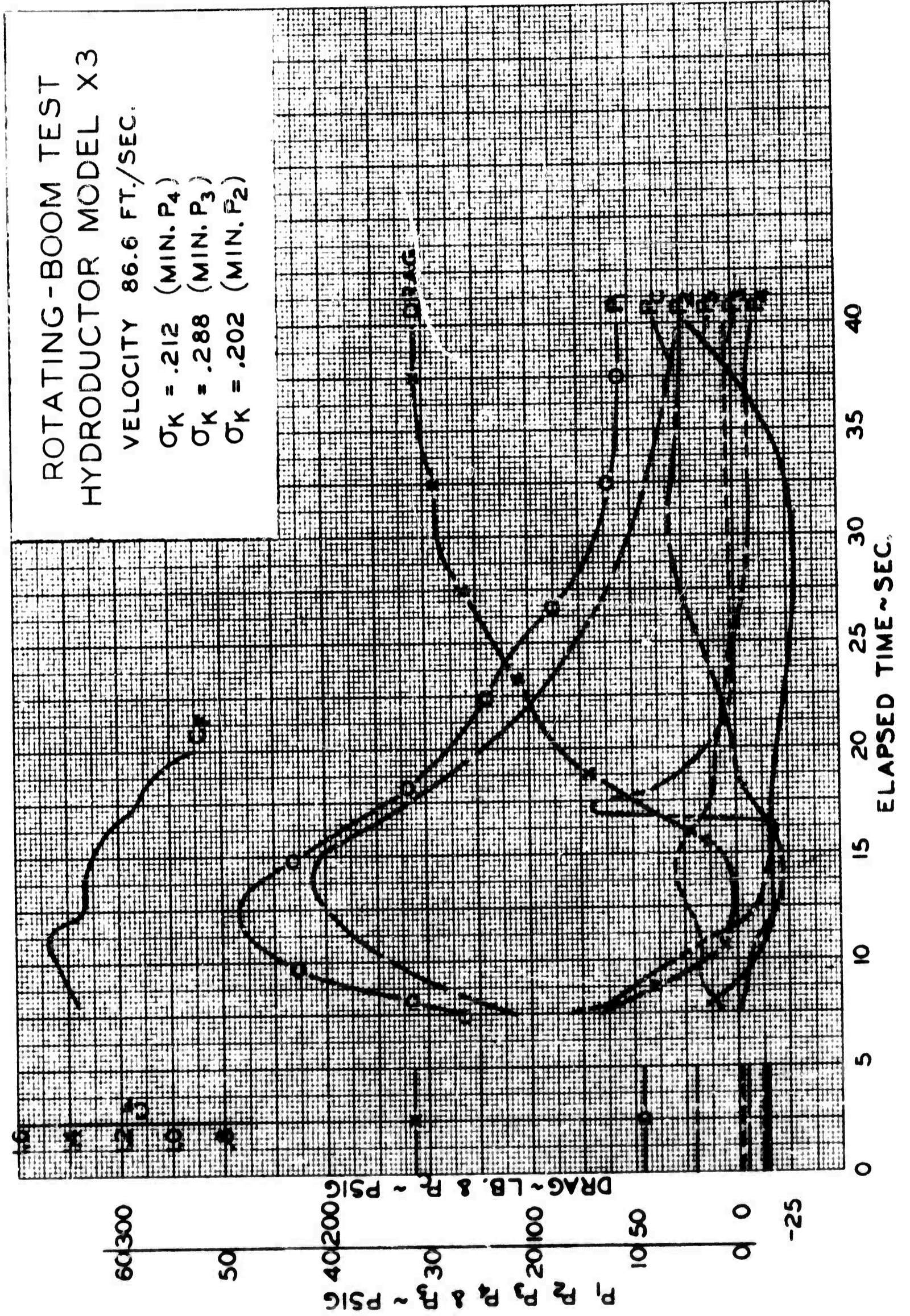
Model X8 Afterbody (Top) and Model X7 Afterbody (Bottom)

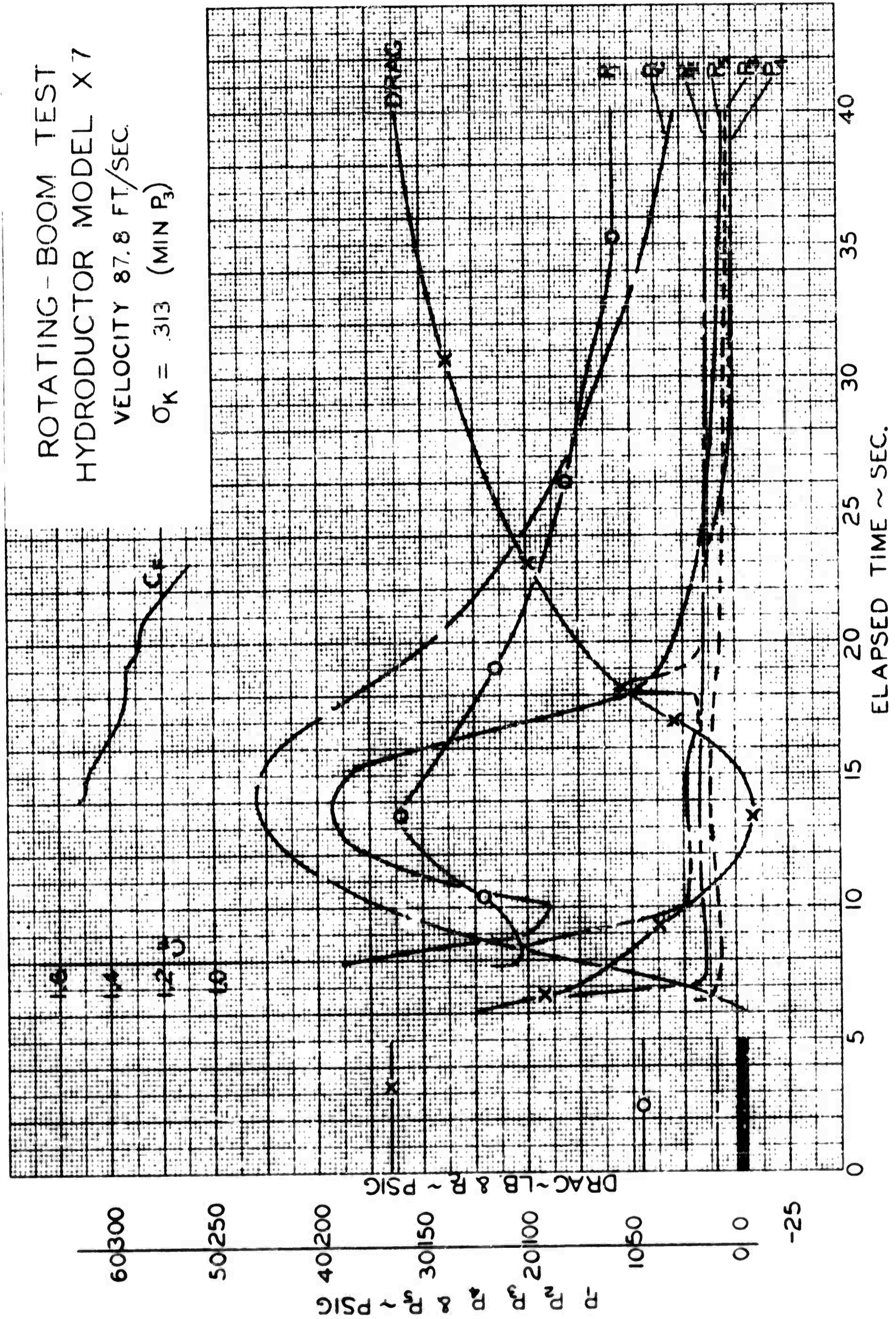
E.S./R.V. 8-20-57 UEC 4846



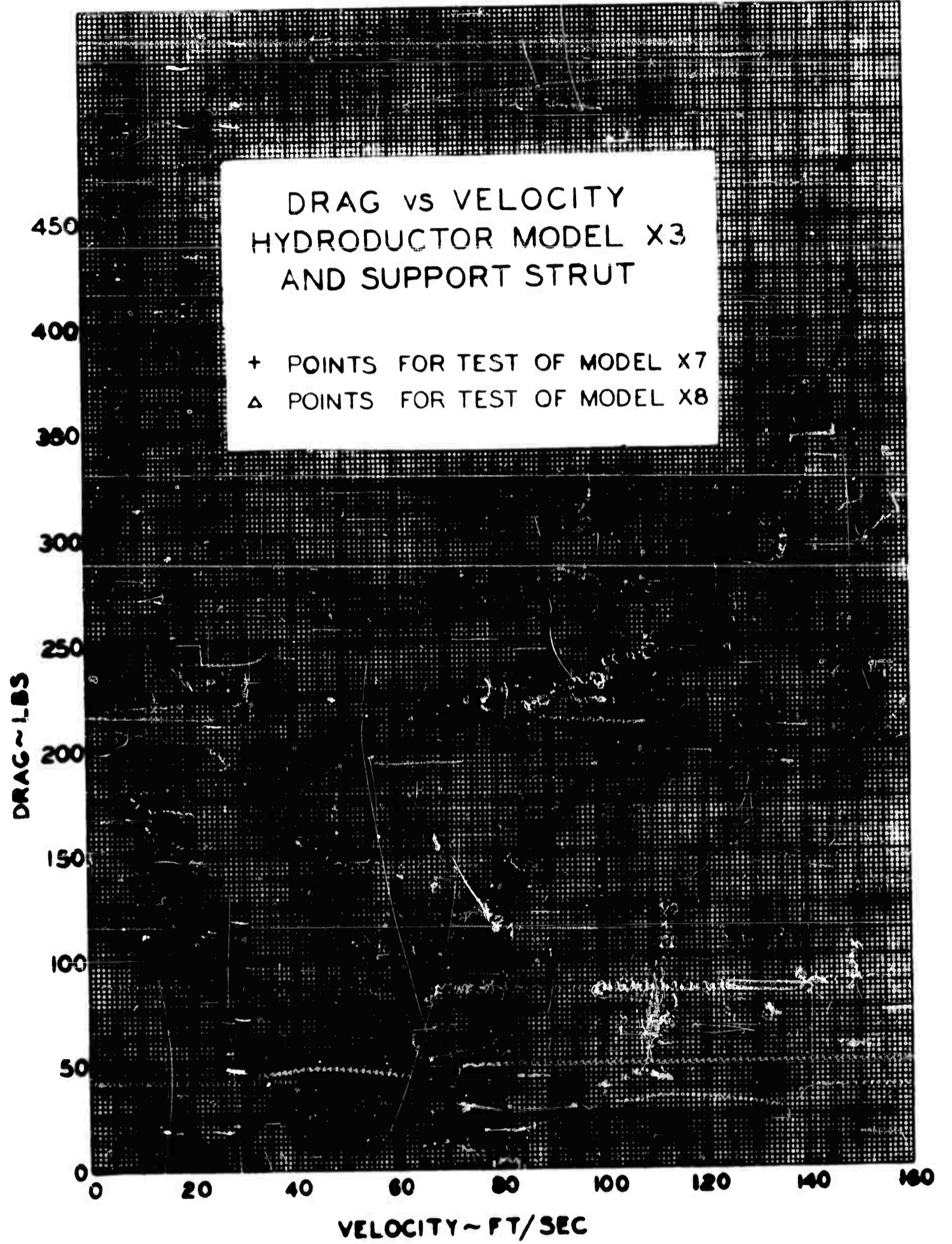
EXTERNAL - CONDENSING HYDRODUCTOR
MODELS X7 & X8
LOCATION OF PRESSURE - SENSING POINTS

E.H./R.V. 6.24-57 VEC 4792

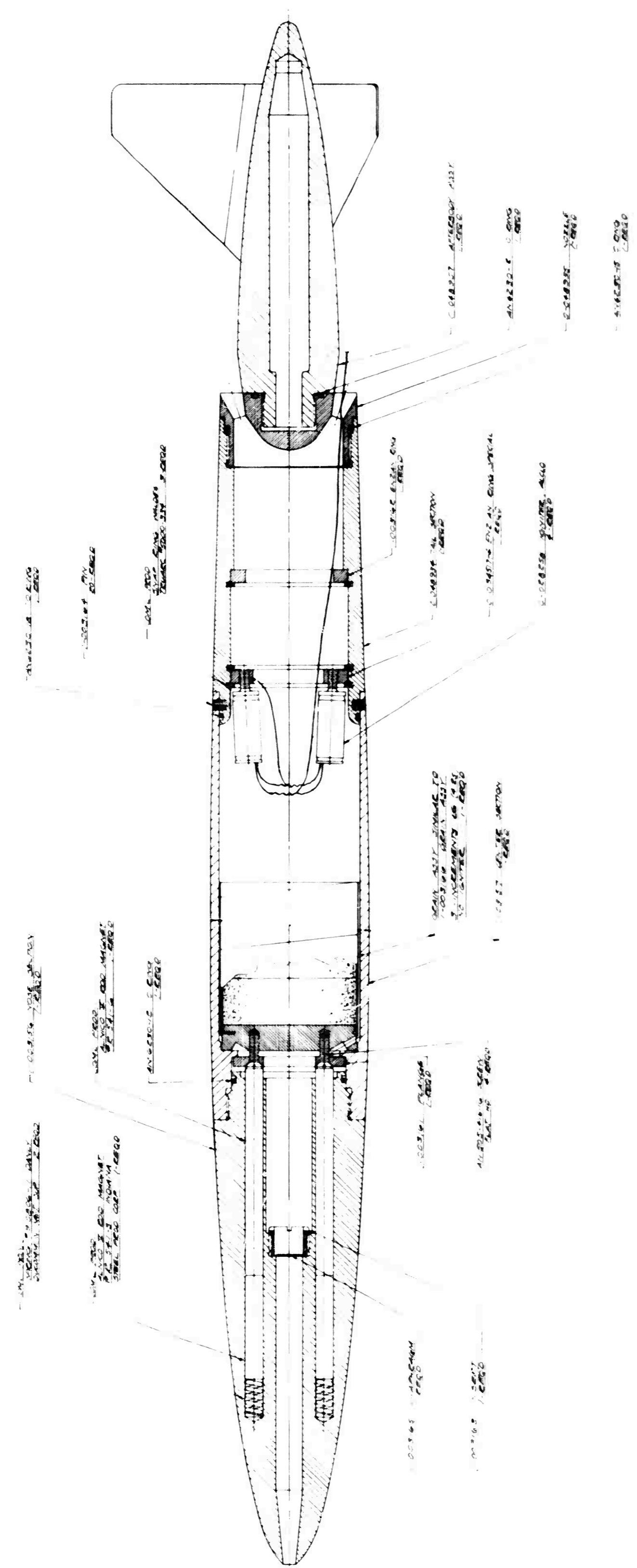




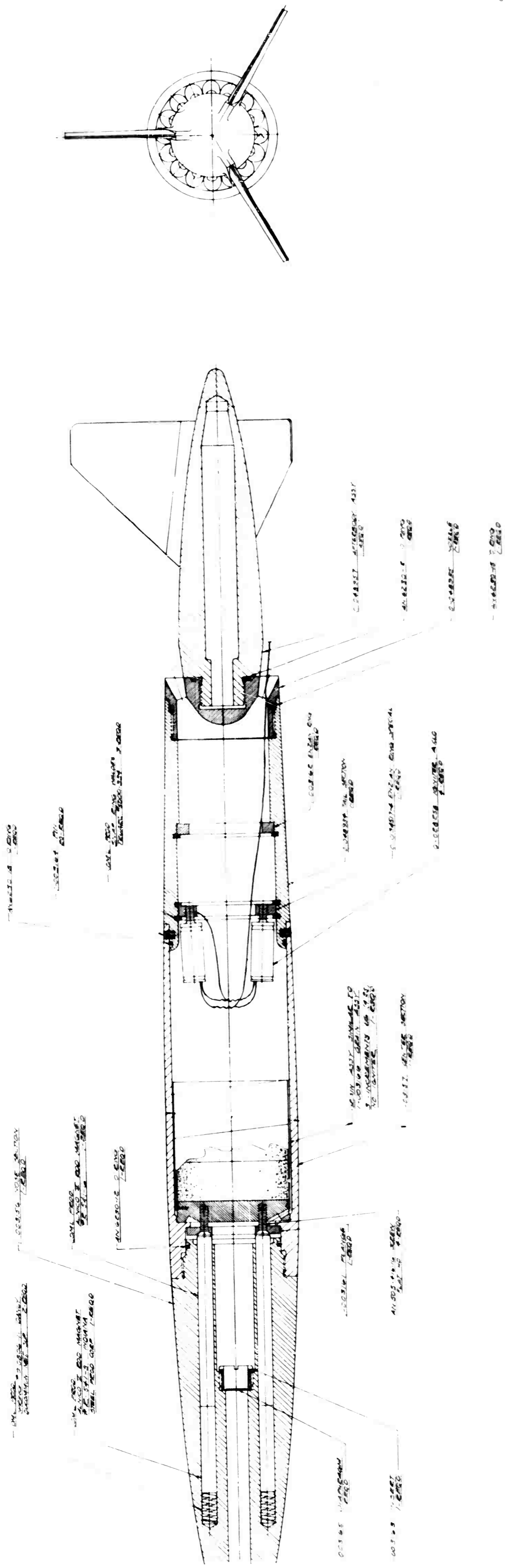
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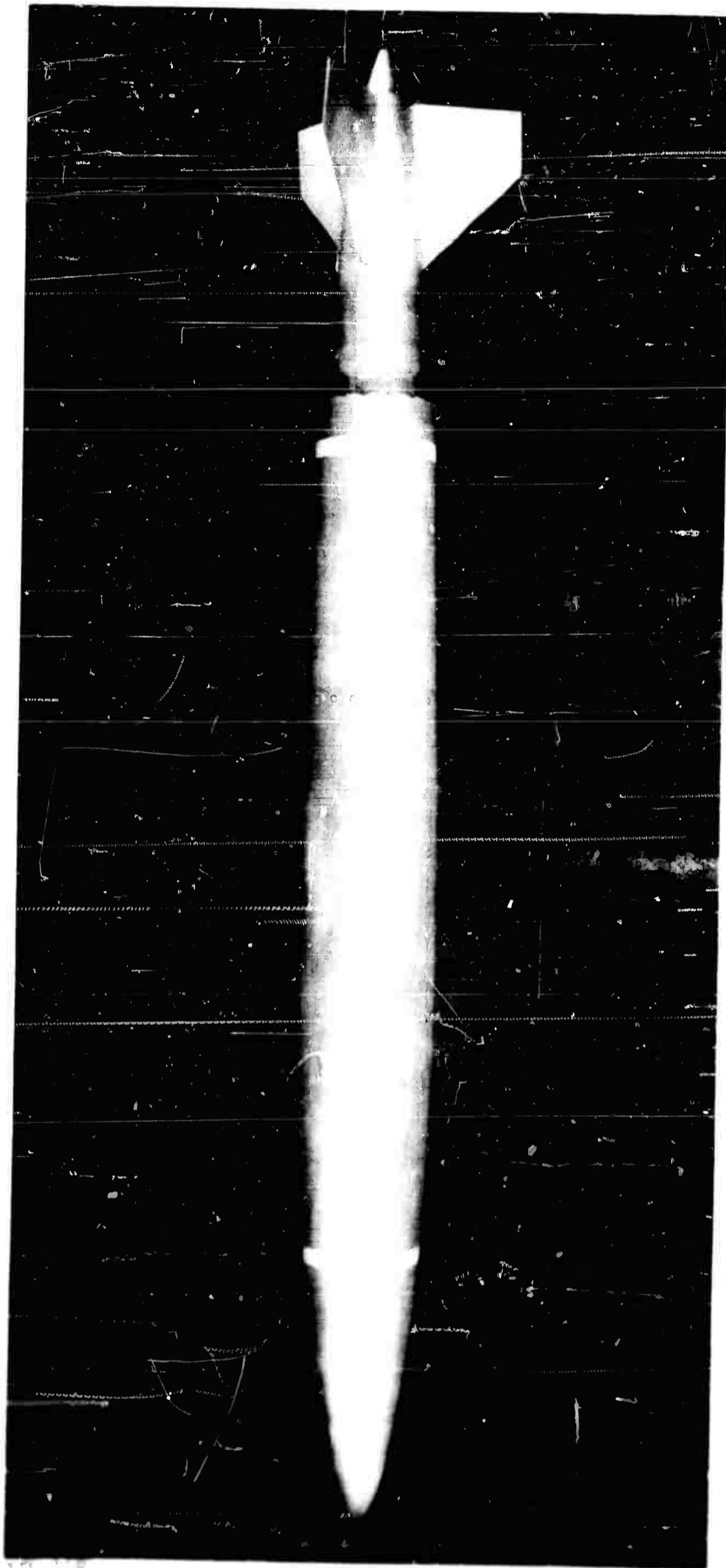


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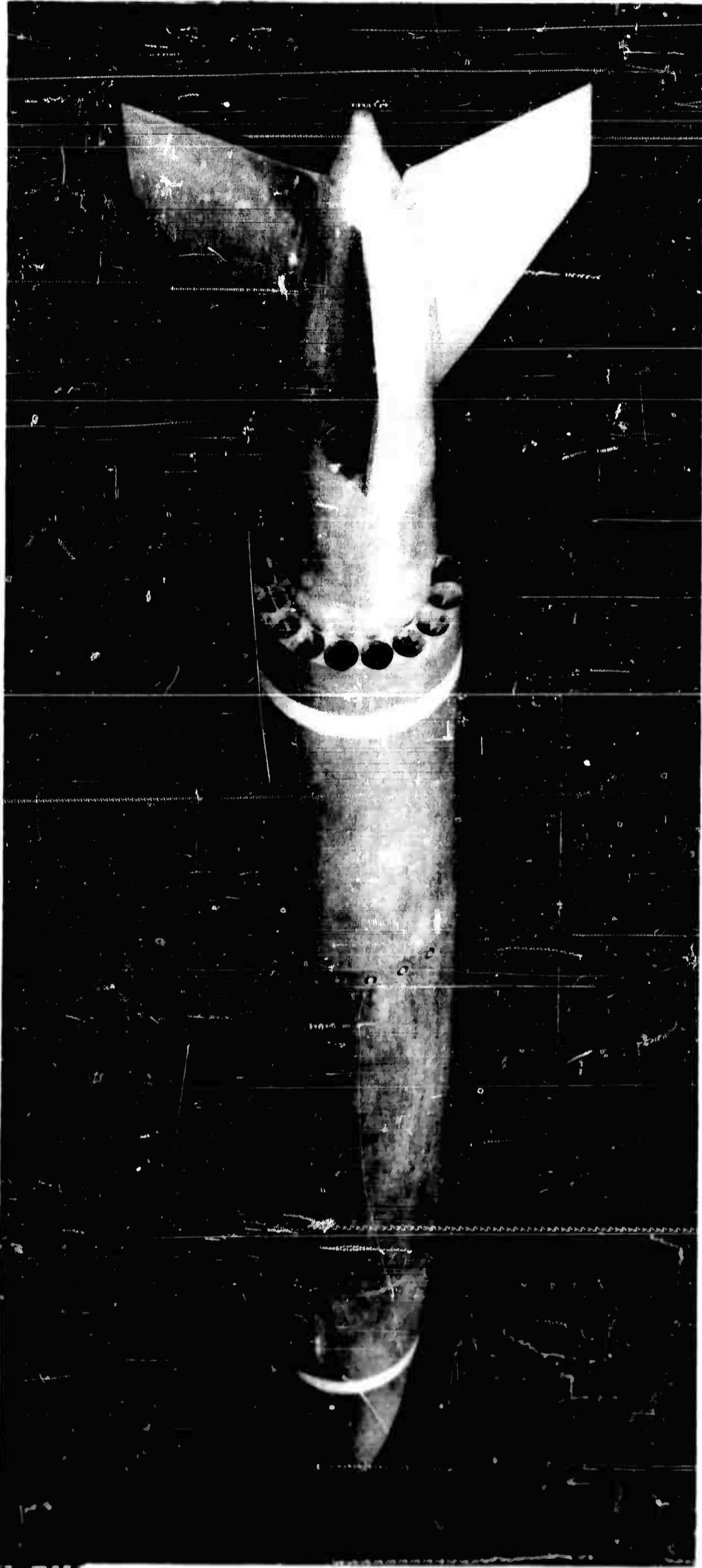


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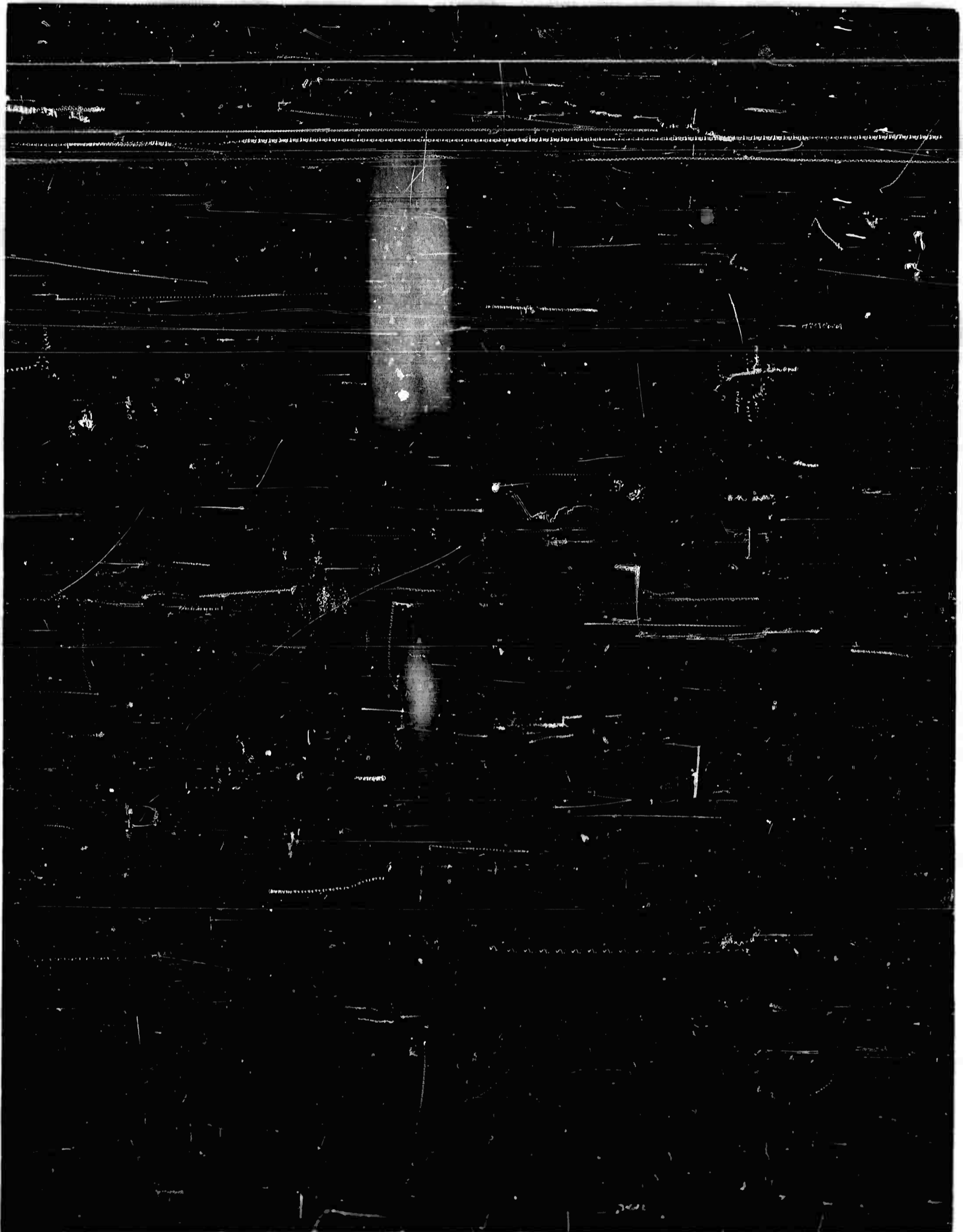
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REVISIONS			
NO.	DESCRIPTION	DATE	BY
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External-Condensing Hydrocarbon Missiles (side view)

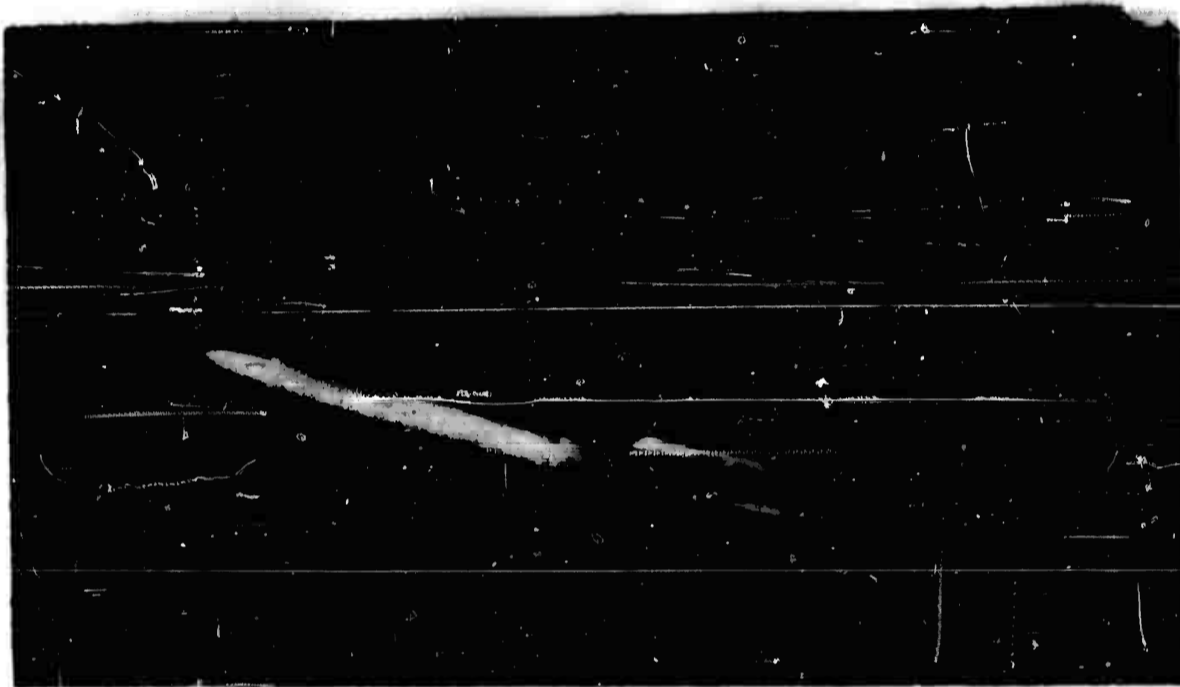
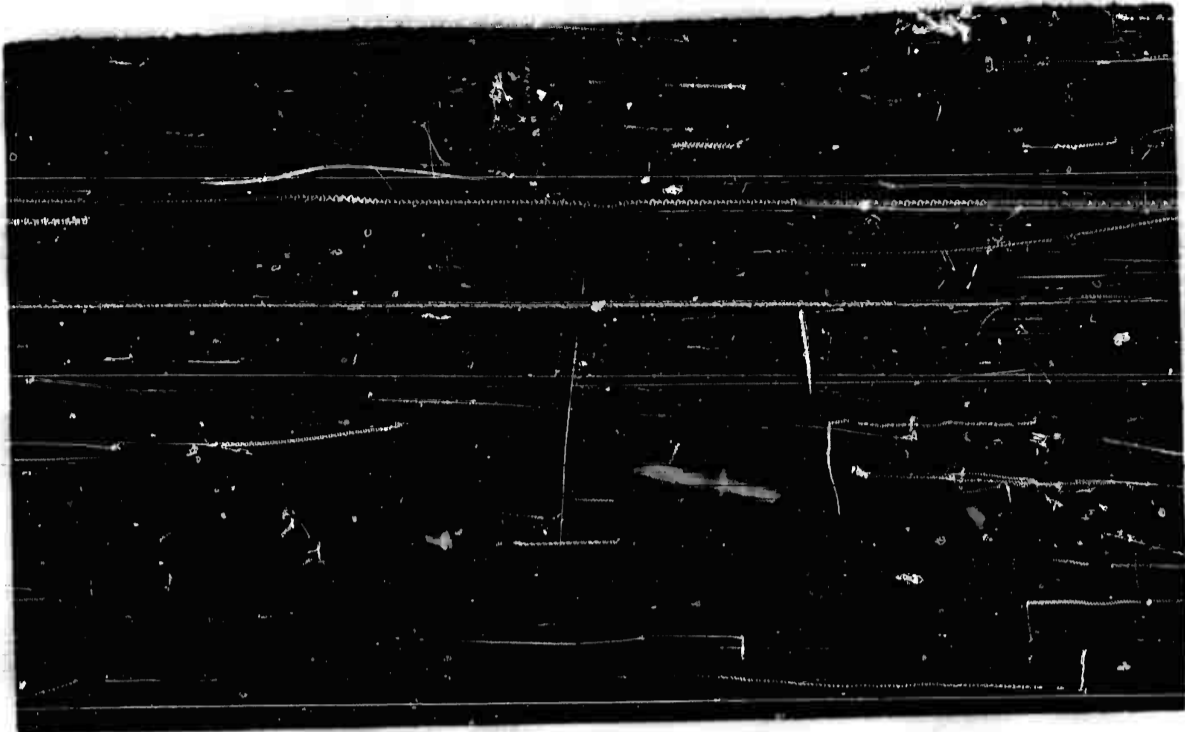


External-Compensing Hydroductor Test Missile (rear view)



Microflash Photograph - External-Condensing Hydroductor

158-377



Prints from High-Speed Motion Picture Film

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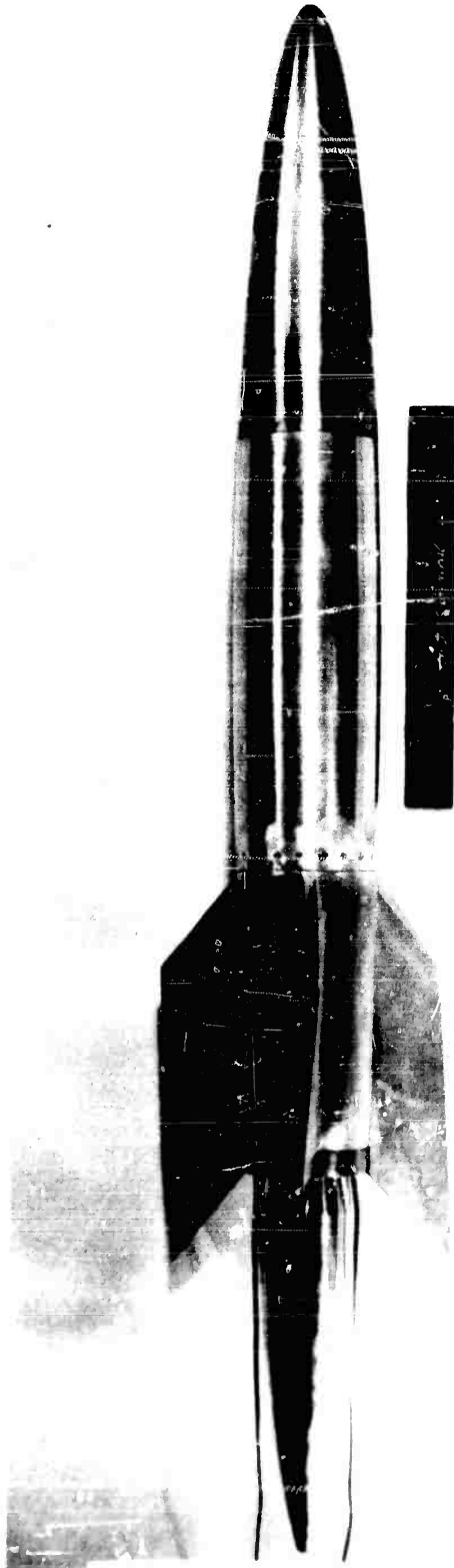
Report No. 1582



Print from Fastax Film Showing Missile Fins

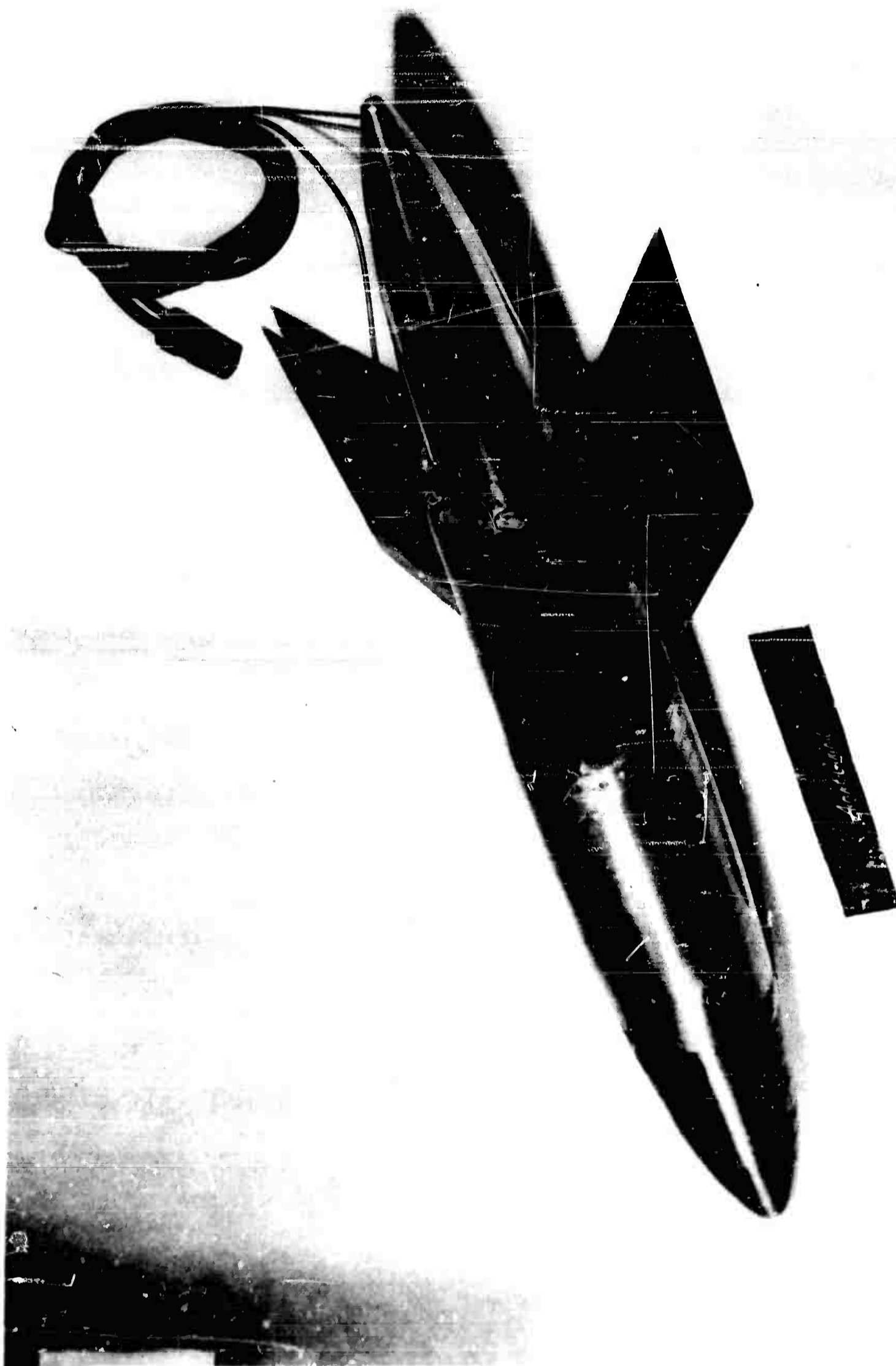
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Figure 35



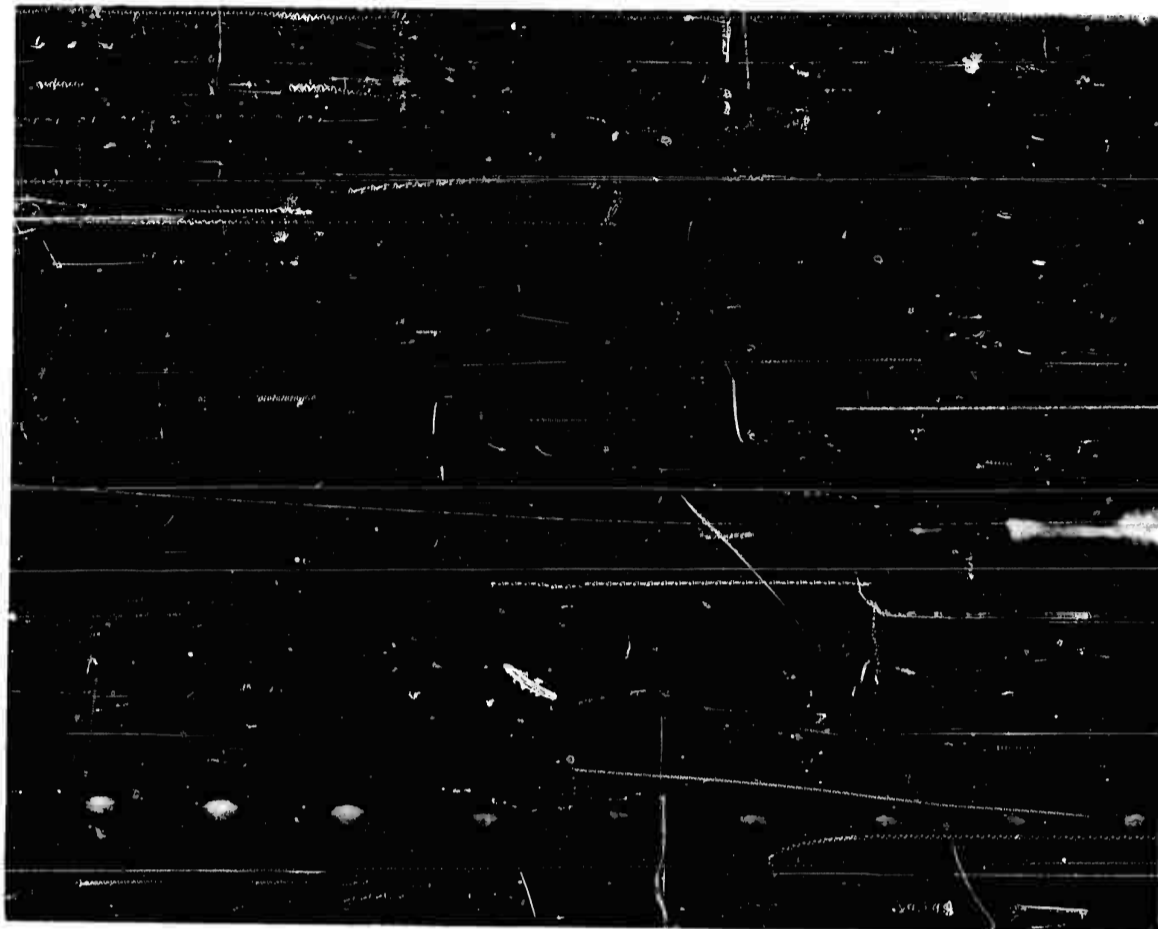
External Condensing Hydroductor Test Missile Model - Side View

658-311

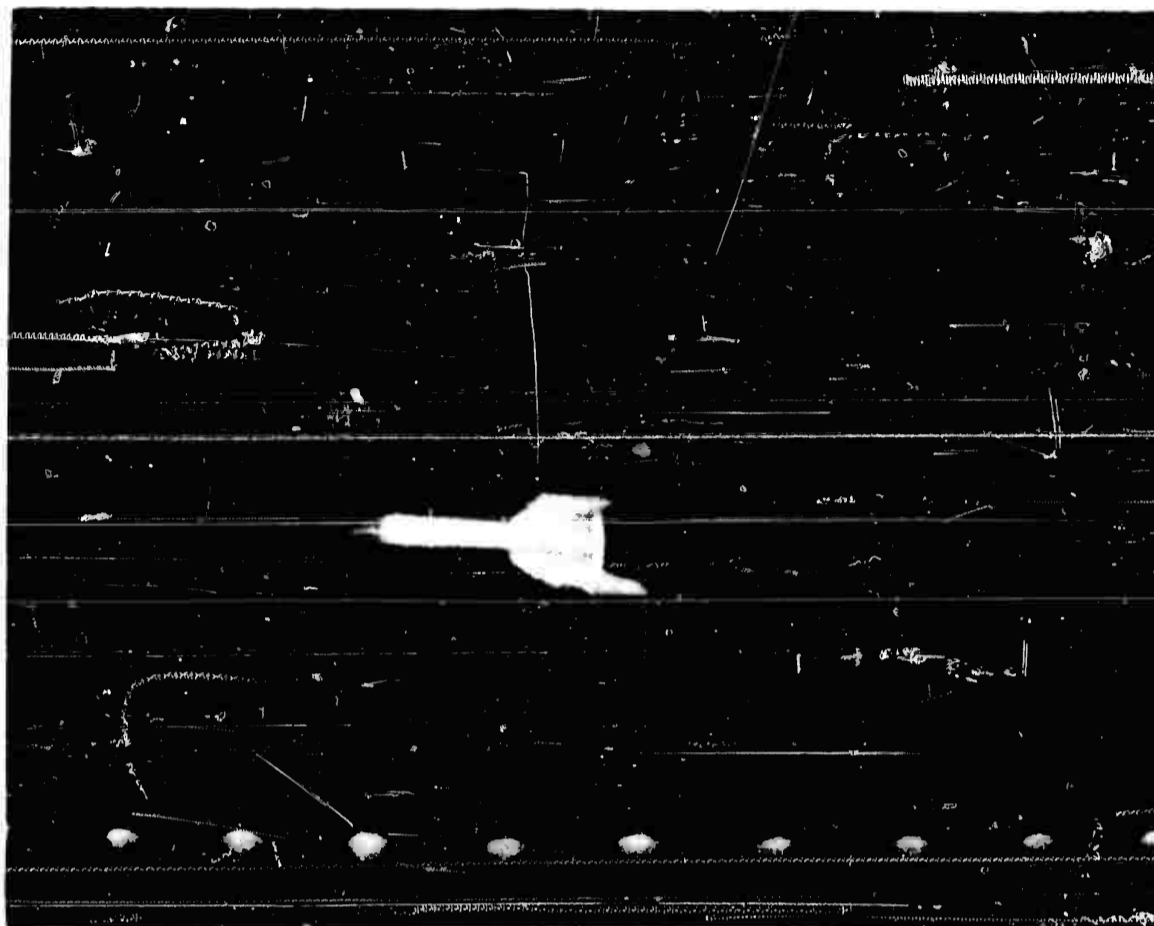


External Condensing Hydroductor Test Missile Model - Rear View

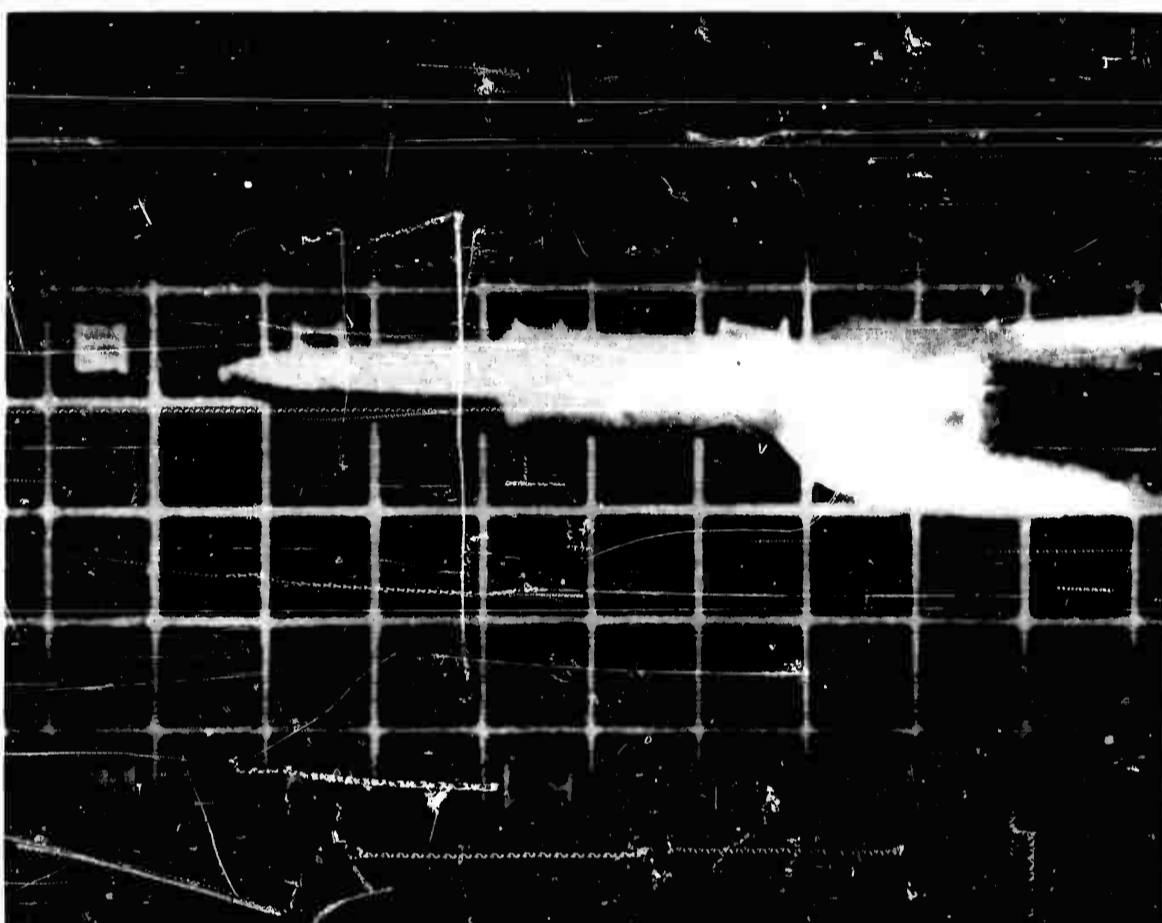
698-312



Prints from High-Speed Motion-Picture Film



Prints from High-Speed Motion-Picture Film



Print from High-Speed Motion-Picture Film - 25-mm Lens



4.5 in. ALCLO Hydroduct Test Missile

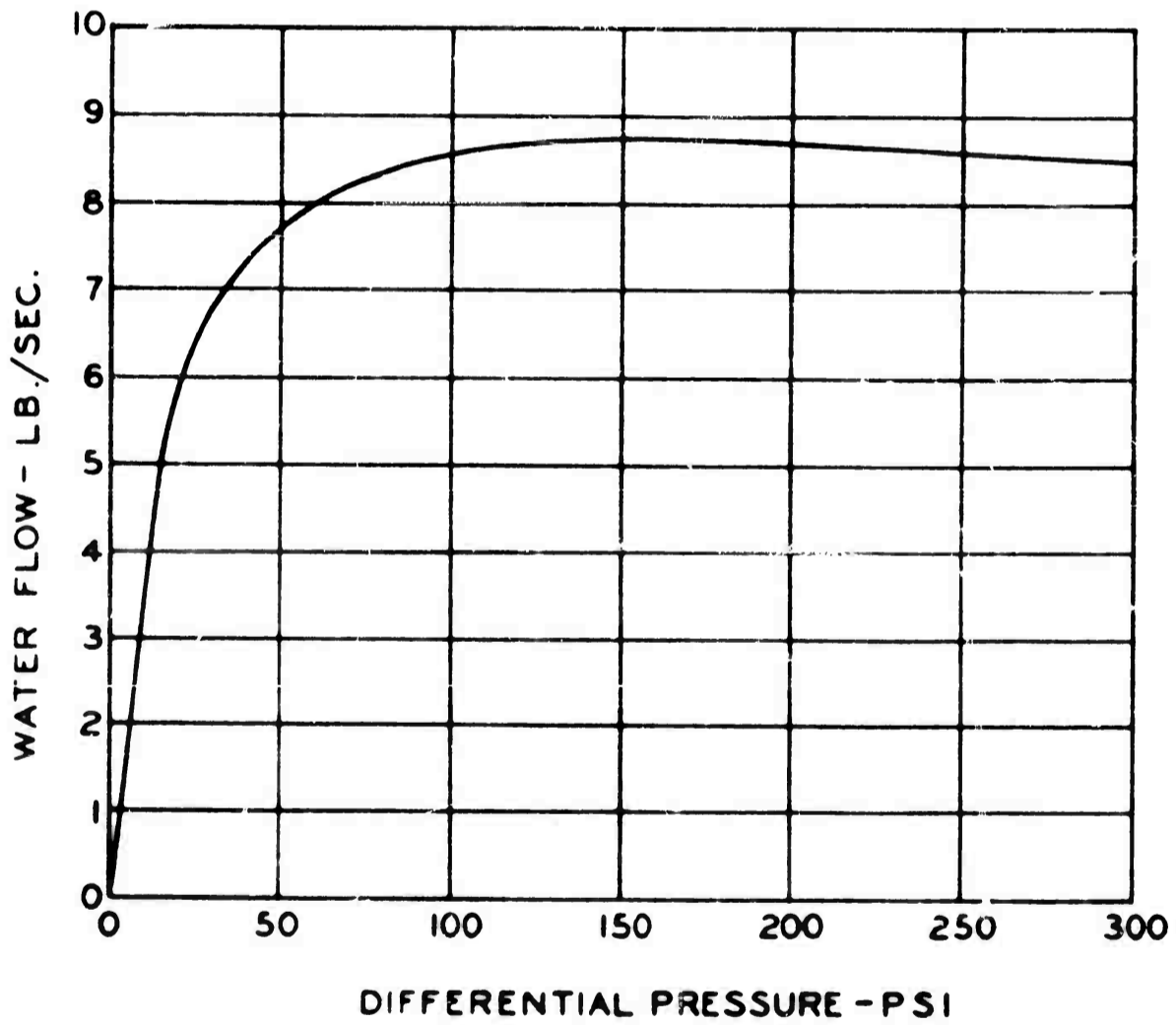


External-Condensing Hydroductor Test Missile with Regular Afterbody

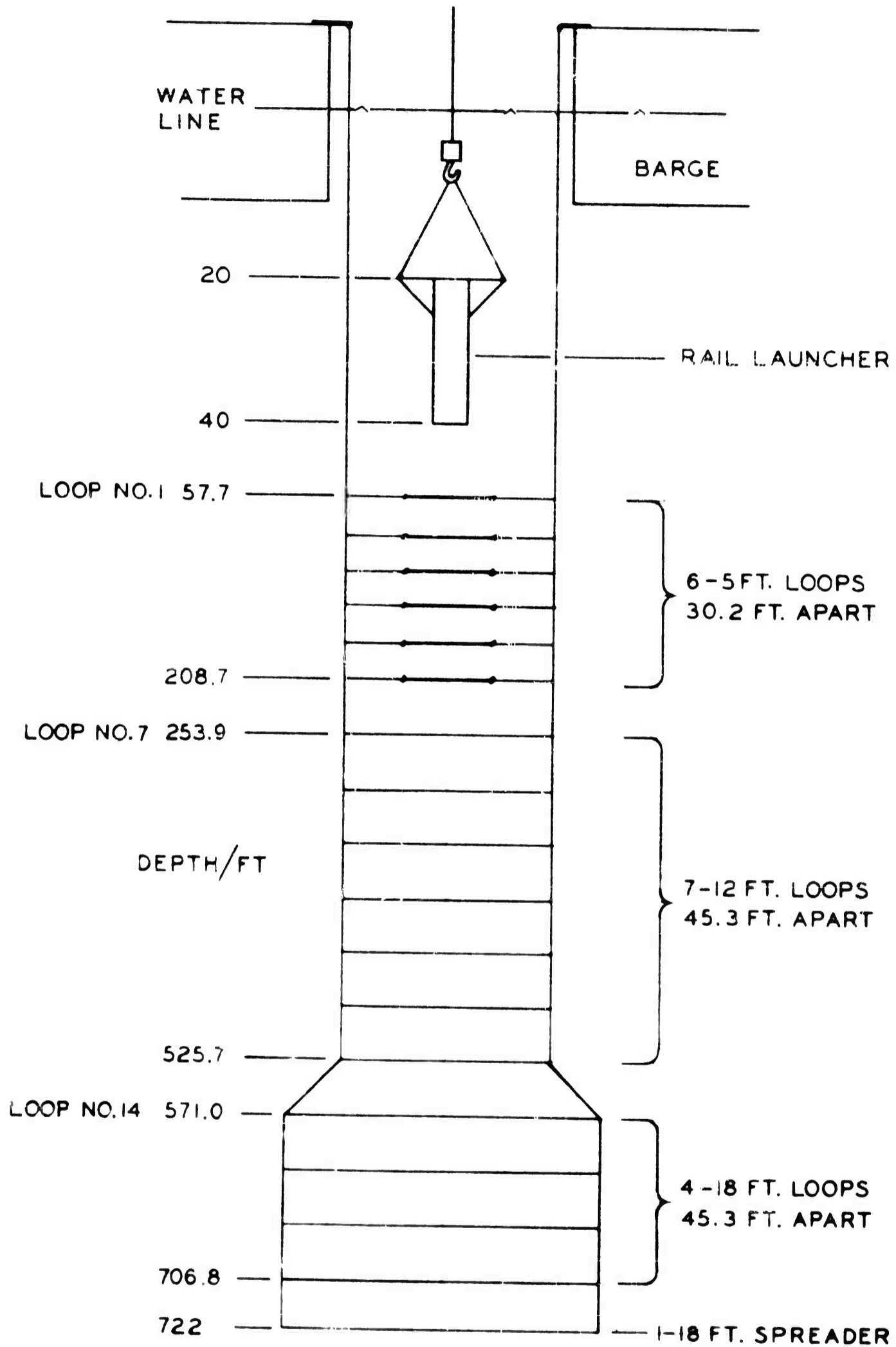
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VEC 5010 9-4-58 RMY

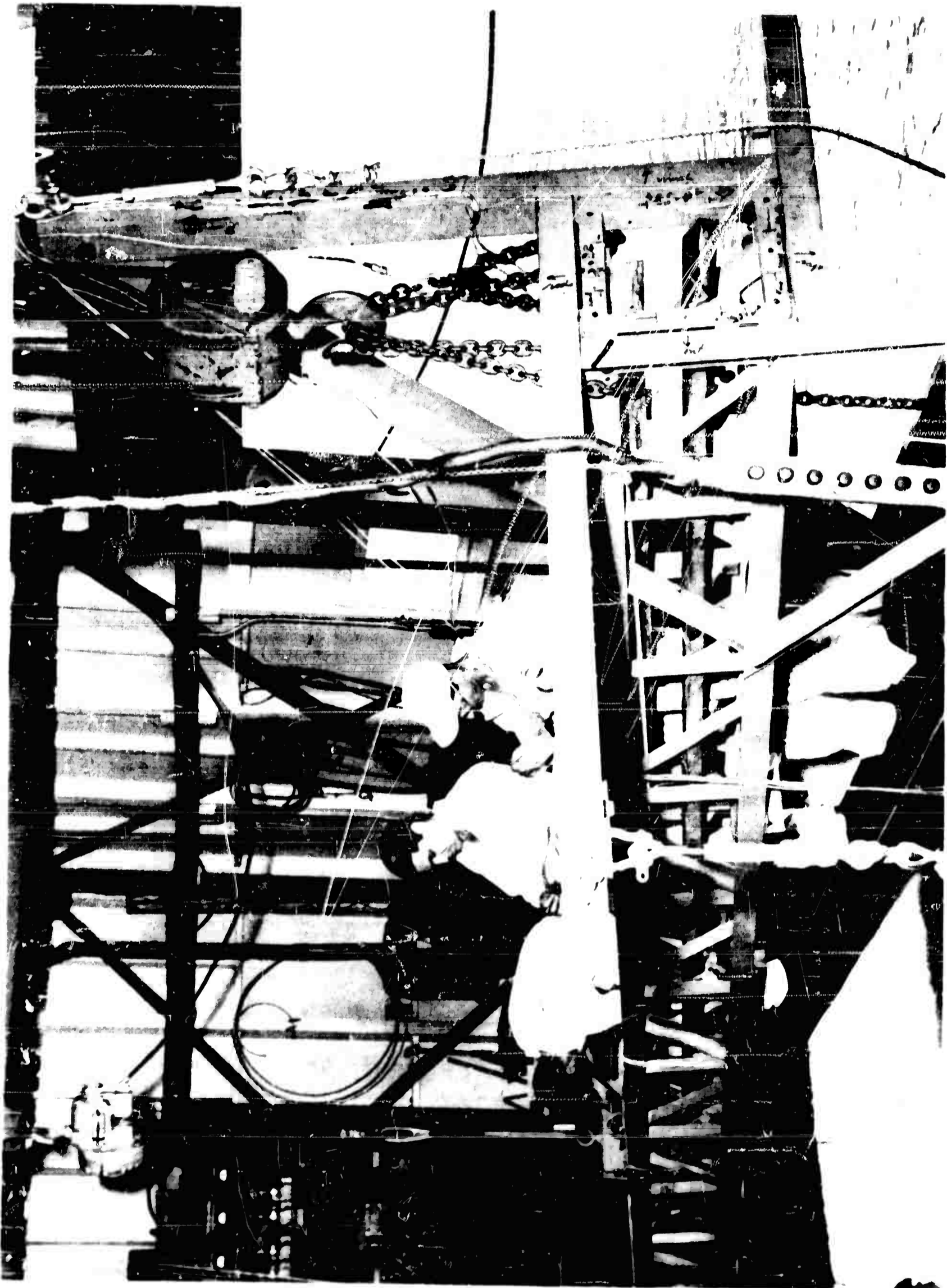
FLOW VS DIFFERENTIAL PRESSURE
HYDRODUCTOR FLOW CONTROL VALVE



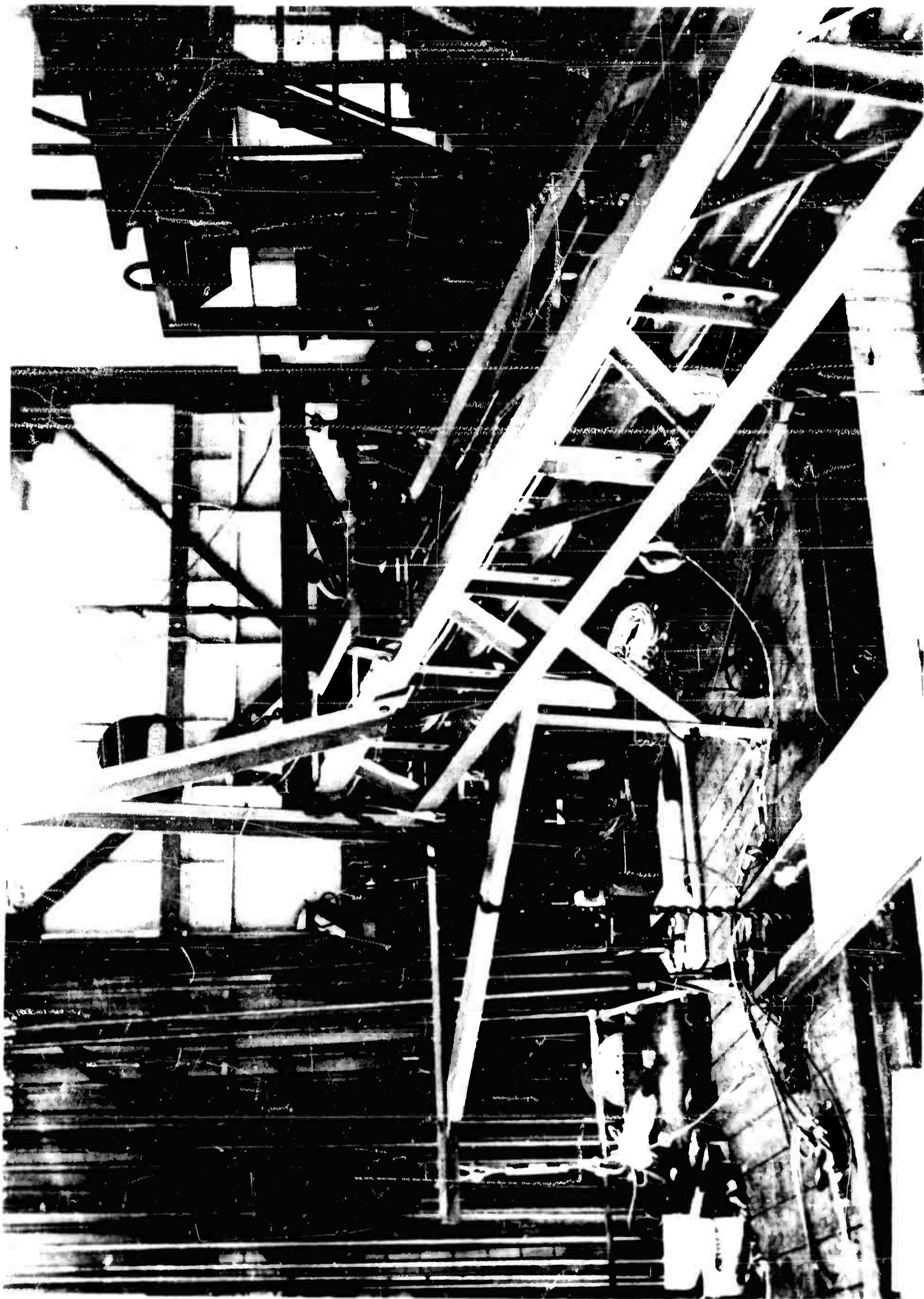
UEC 5011 9-4-58 RMV



SCHEMATIC DIAGRAM
DEEP-WATER RANGE
FOR HYDRODUCTOR TESTS



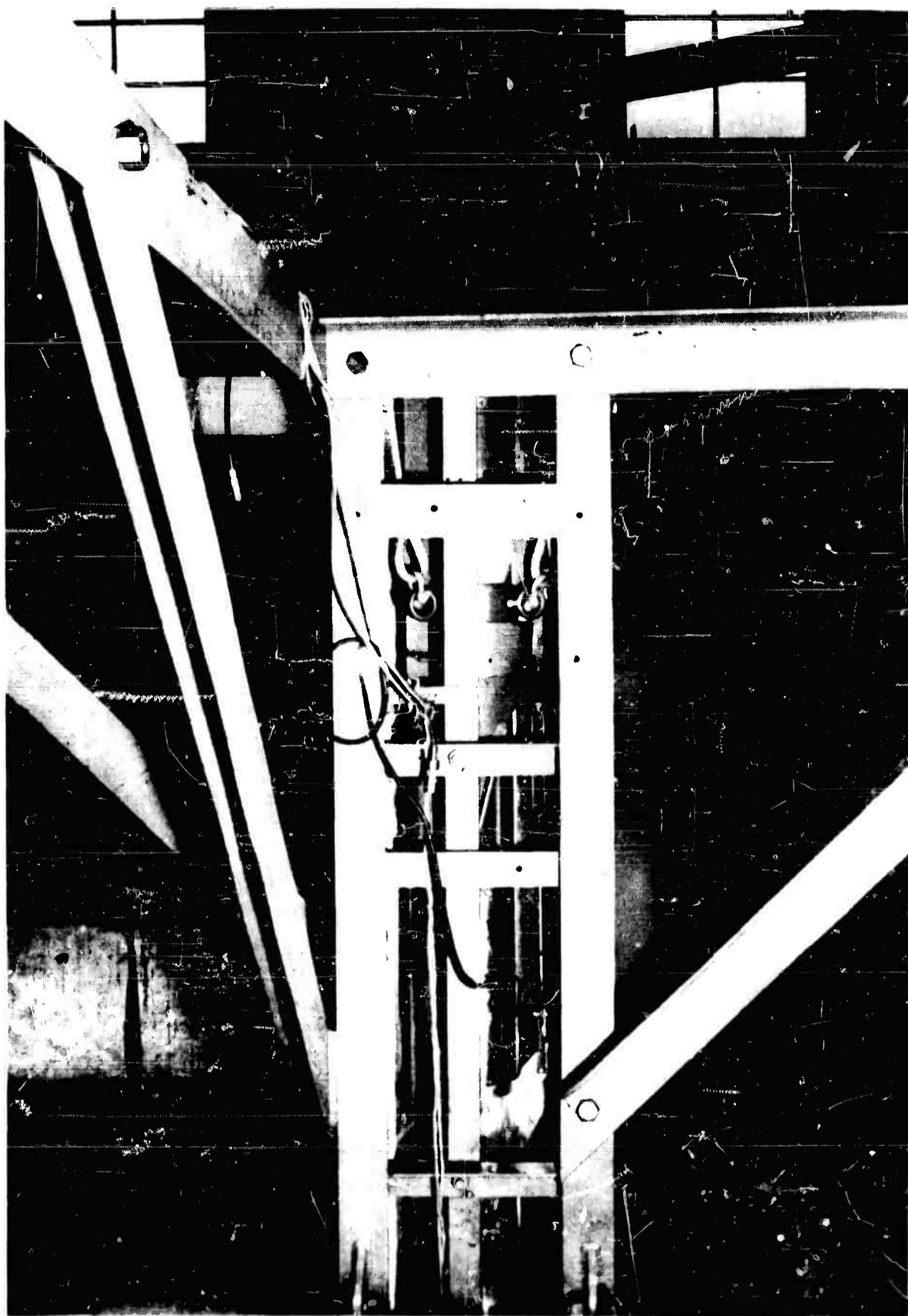
Rail Launcher in Horizontal Loading Position



Rail Launcher in Horizontal Loading Position - View from Muzzle End



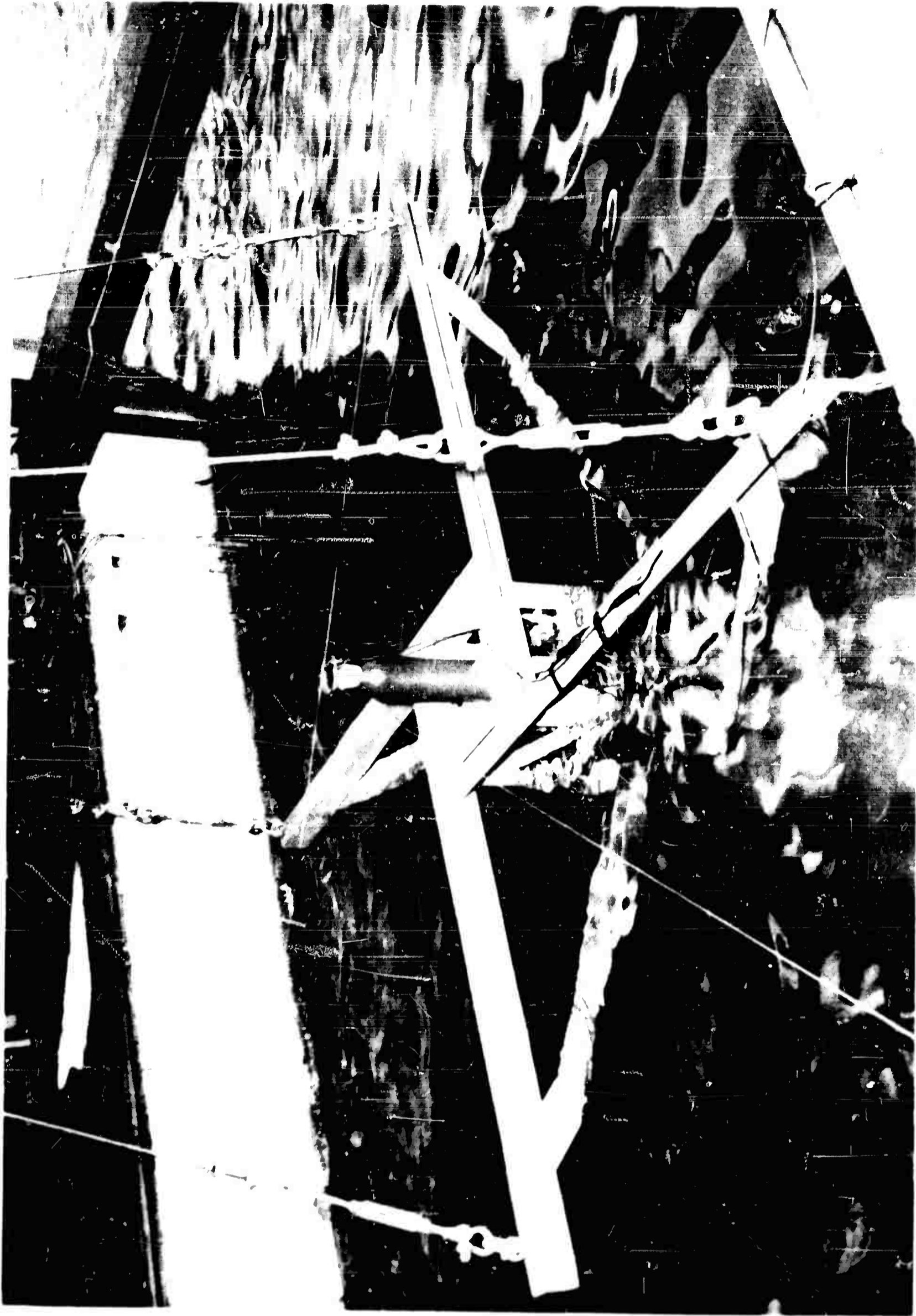
Checking Loading of Test Missile Prior to Lowering in Water



253-847

Launcher in Vertical Position - View of Shear Pin and Booster Adapter

Figure 49



Alignment of Launcher with Center of Loop System. Prior to Submergence

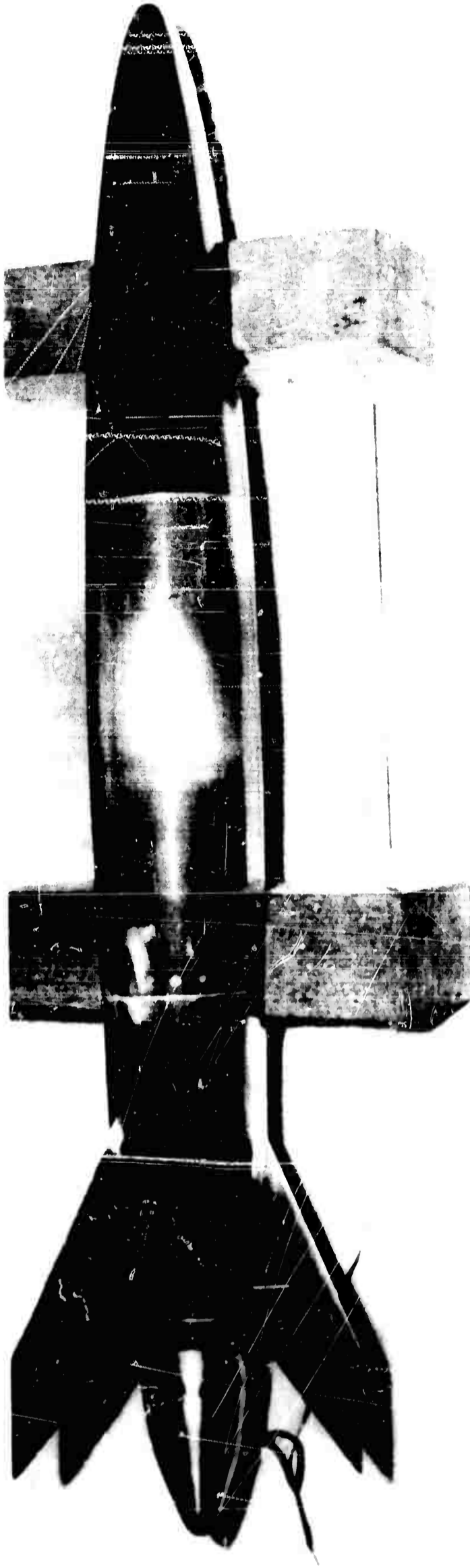


Booster Adapter for Test No. 5



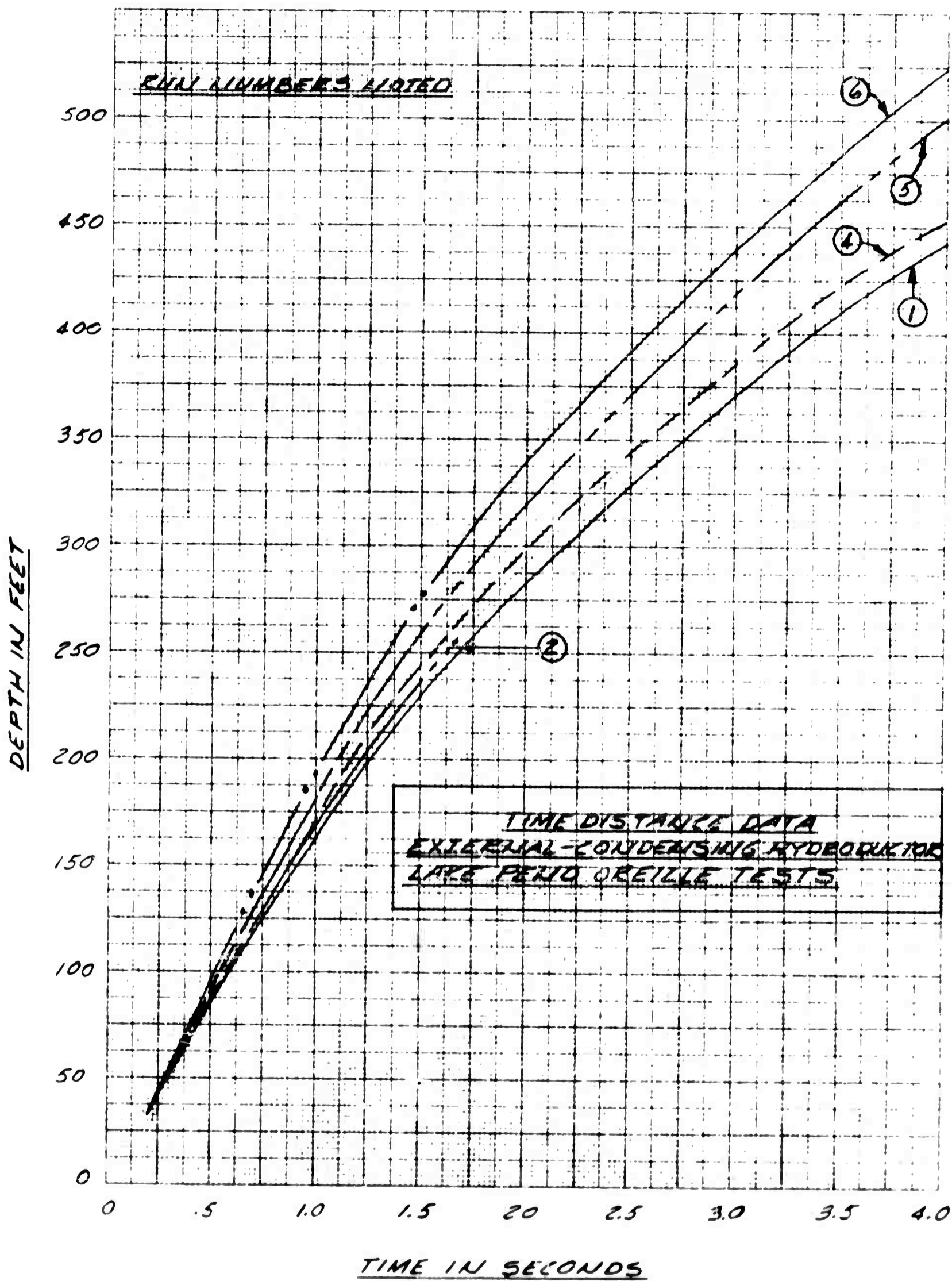
Booster Adapter for Test No. 6

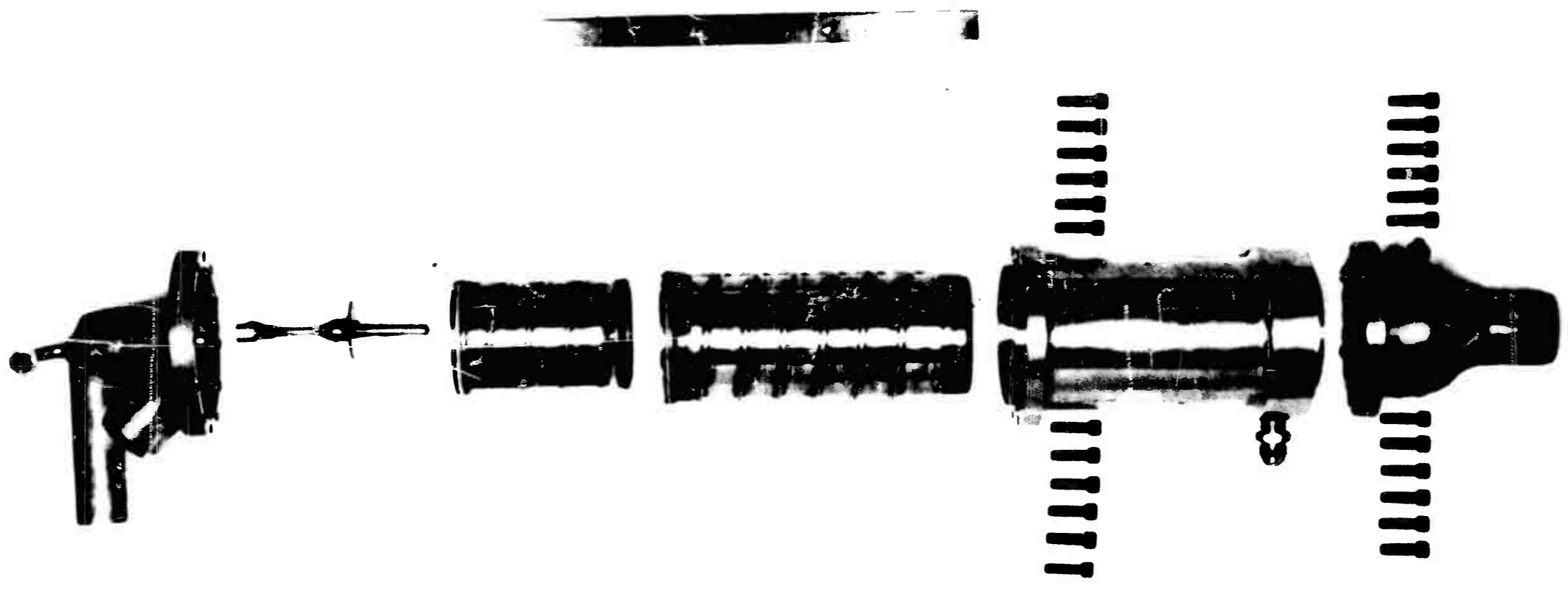
15-501



External-Condensing Hydroductor Test Missile with Short Afterbody

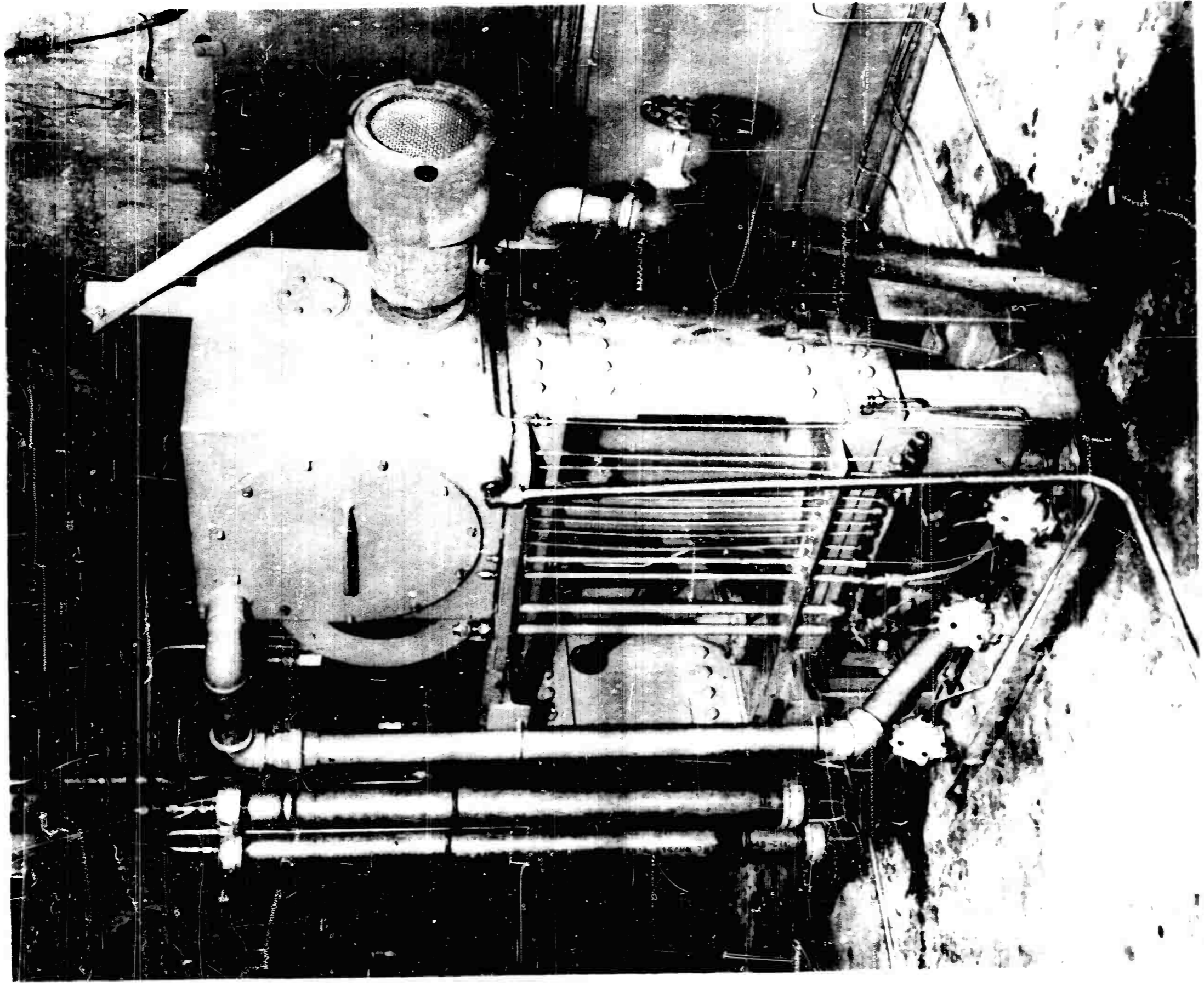
858-860



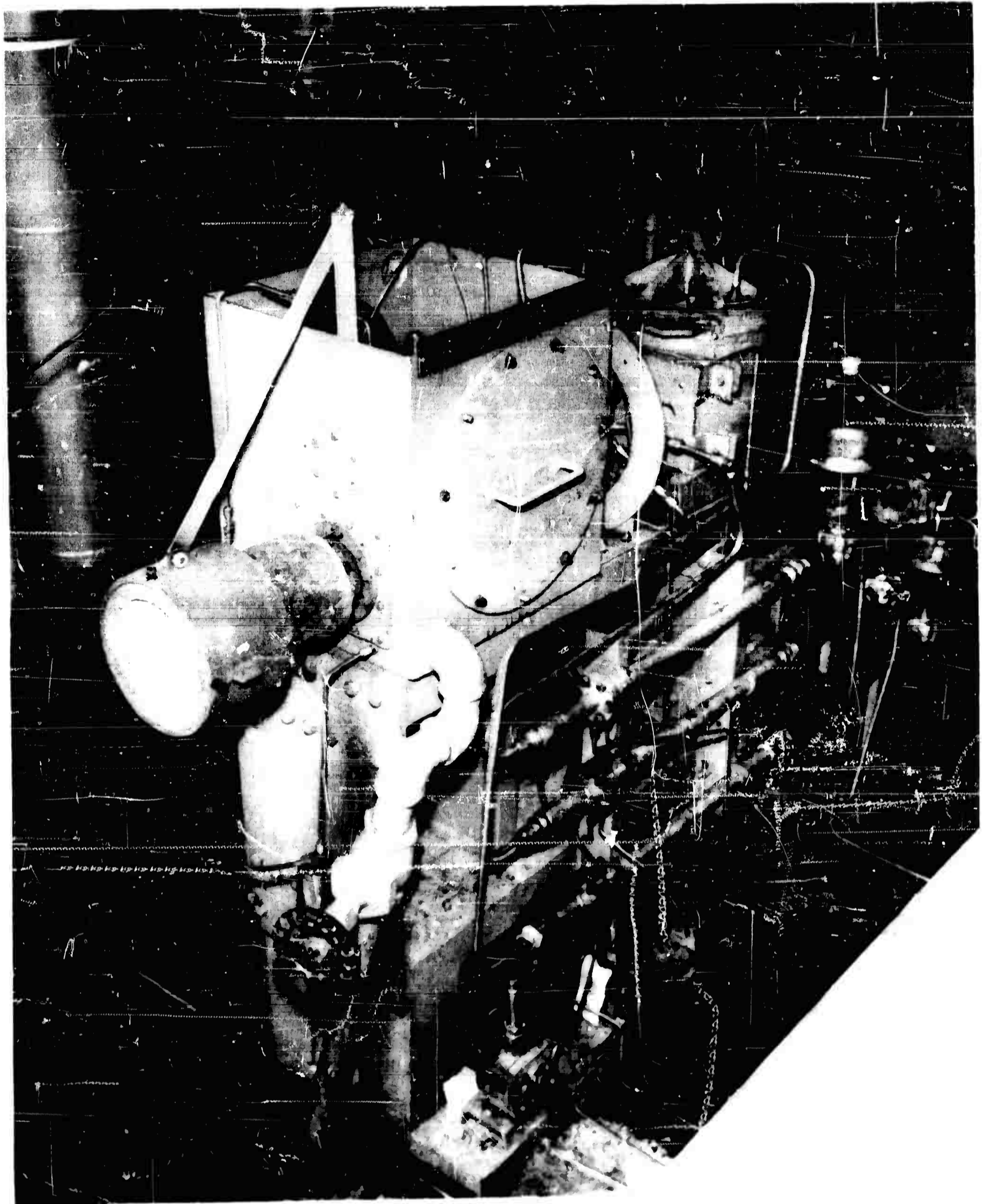


Combustion Chamber of Experimental Design No. 1 Mod 1 for the MK 16-6 Torpedo - - Disassembled View

556-946

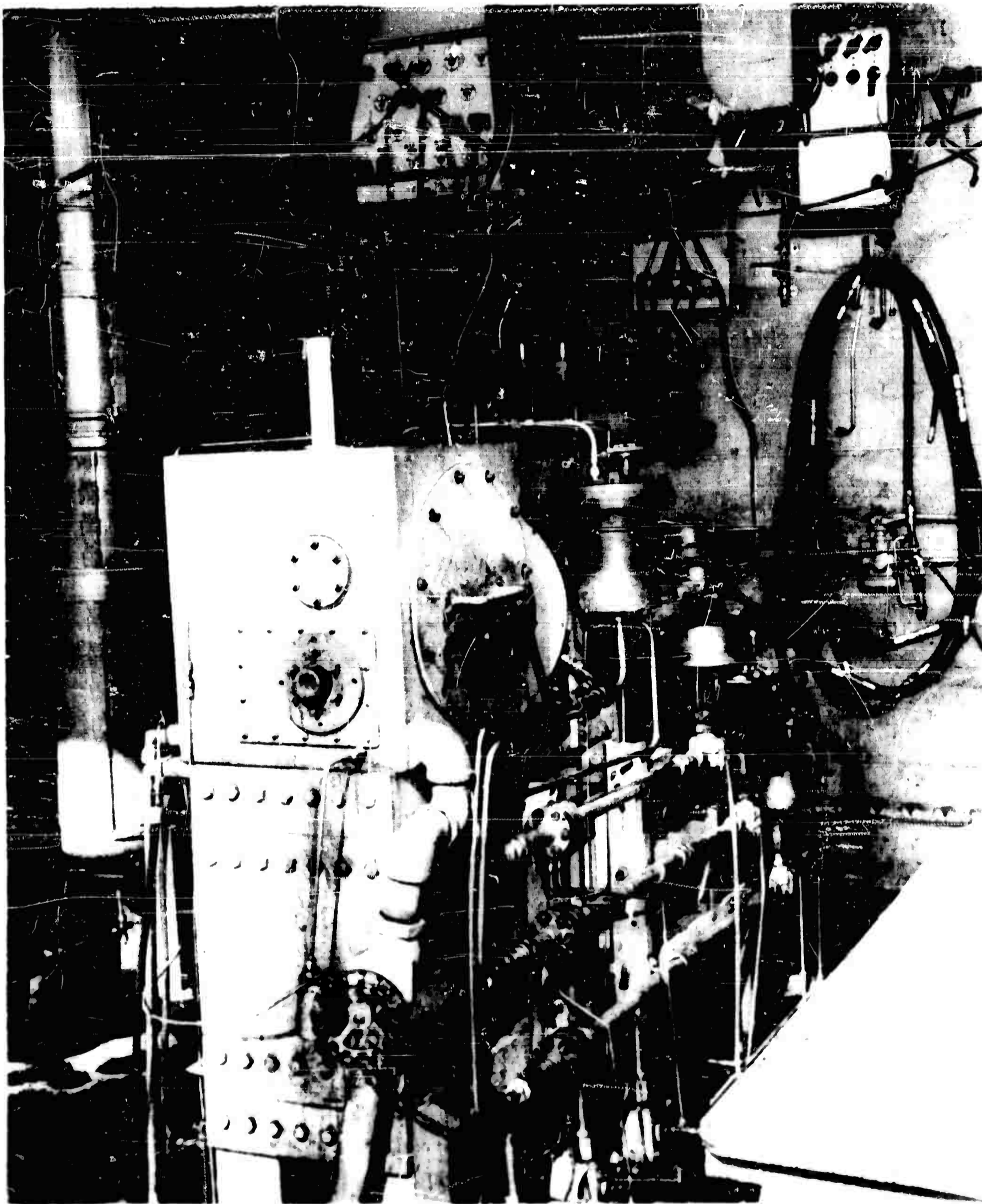


Ion-Exchange Unit - 12.5-in. OD x 5.5 in. on Thrust Stand



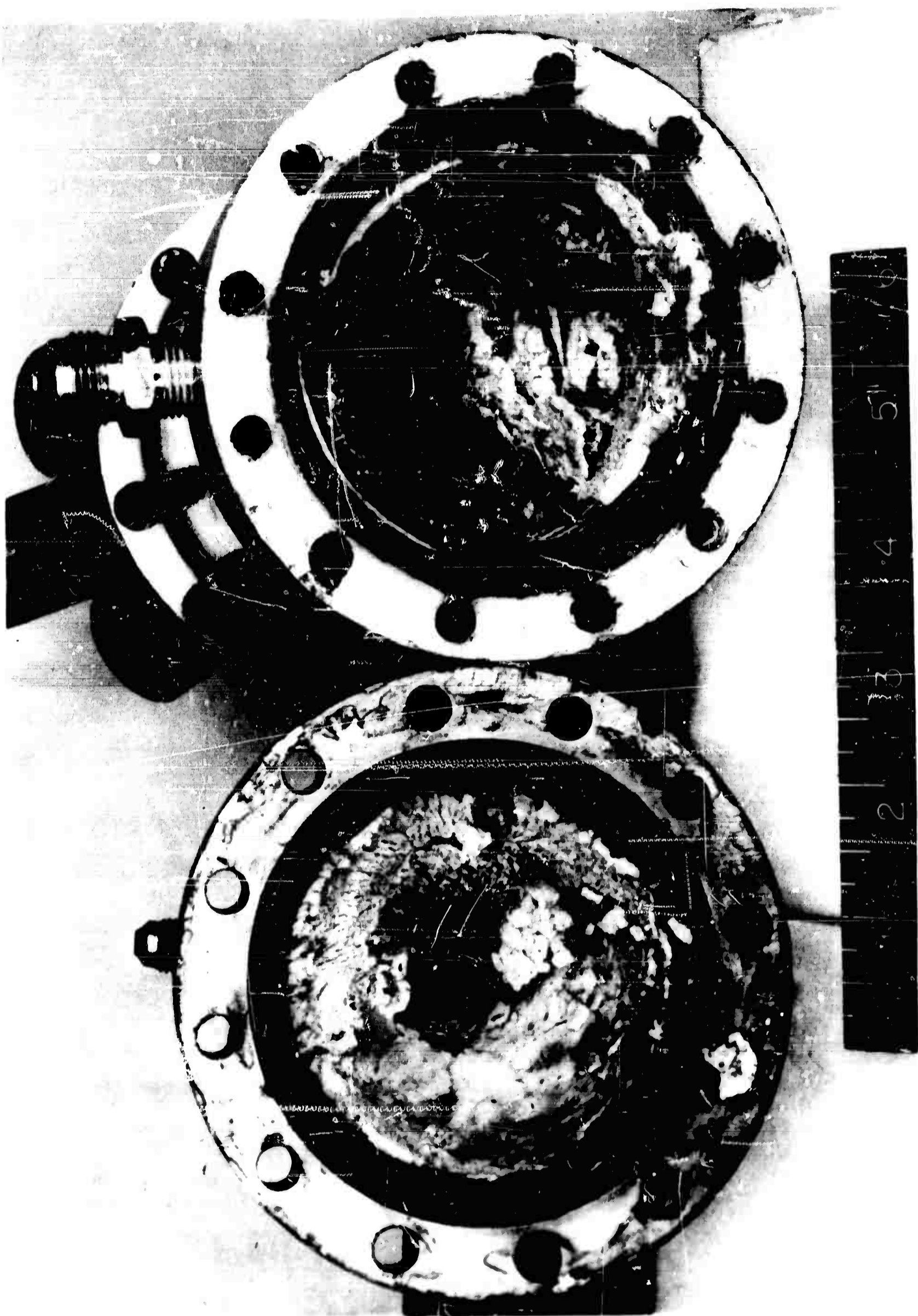
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Ion-Exchange Unit - 3-in. OD x 8 ft on Thrust Stand



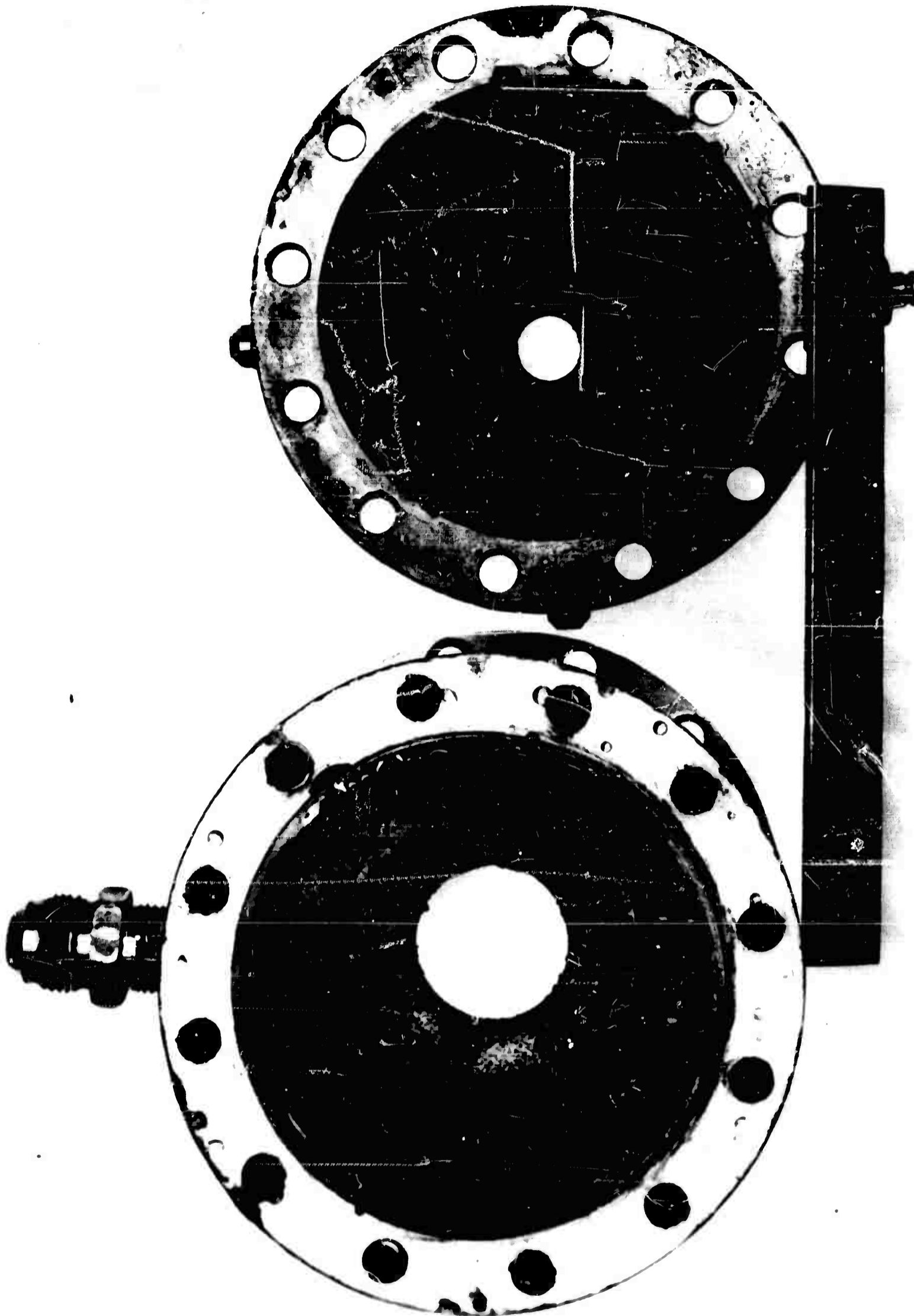
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Ion-Exchange Unit - 6-in. OD x 6 in. on Thrust Stand



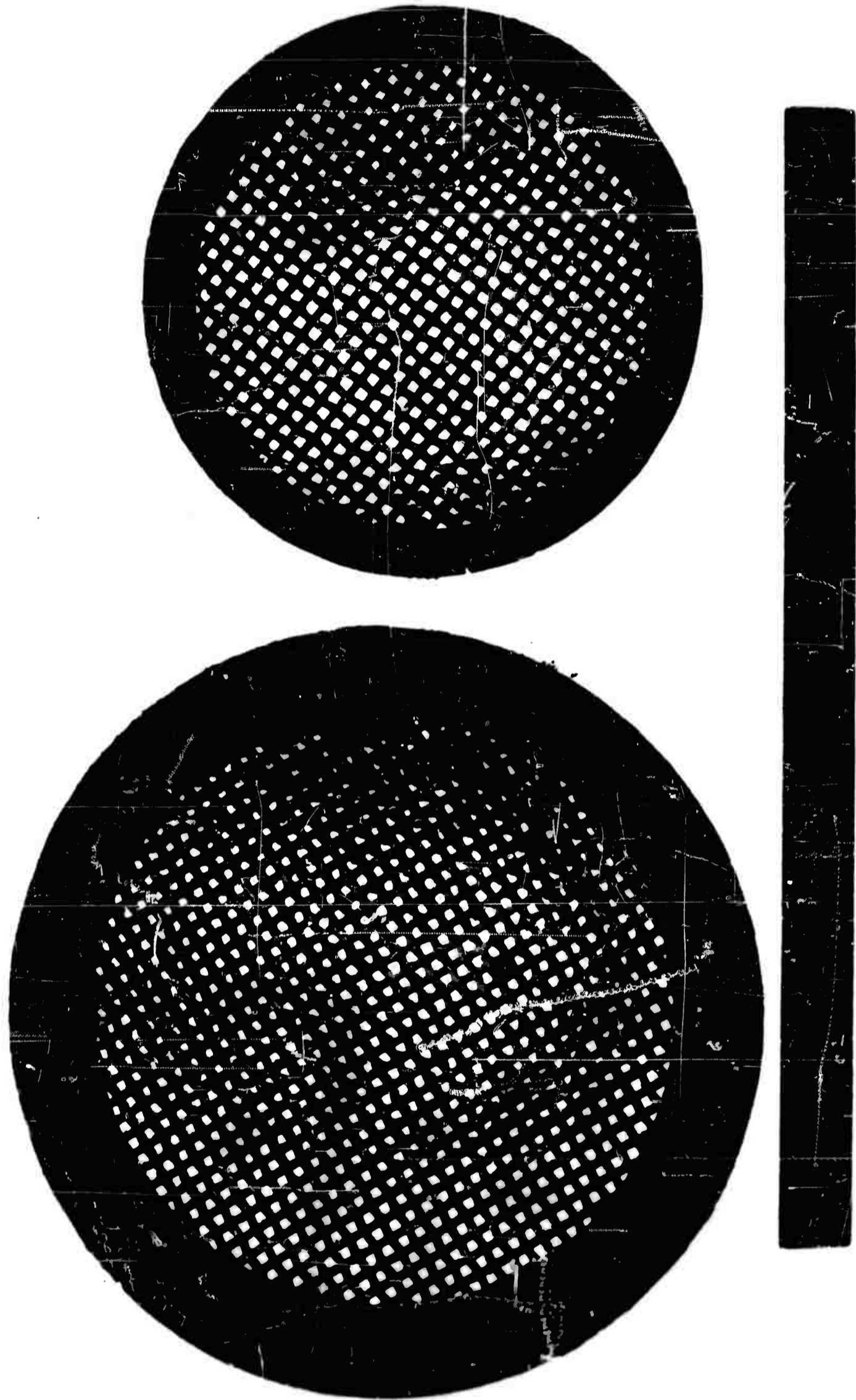
Solids Deposited Inside the Combustion Chamber Using Untreated
Synthesized Sea Water, Run No. 1

756-404



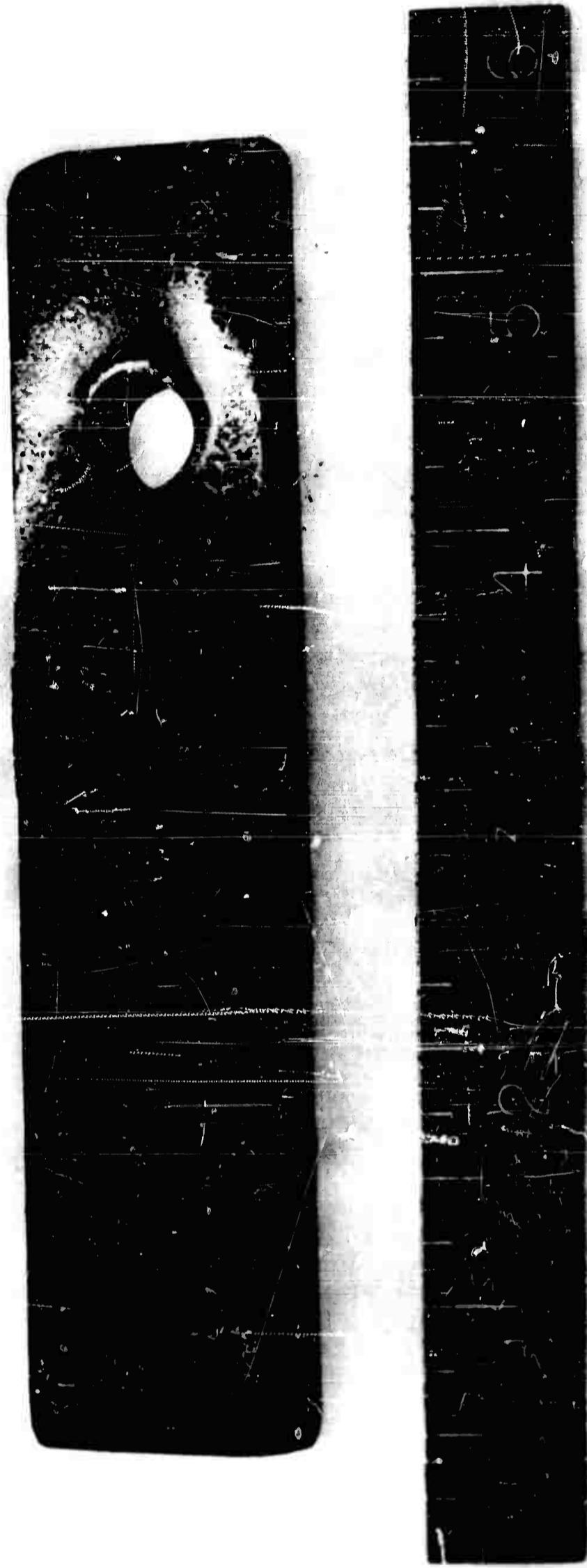
Solids from Untreated Natural Sea Water Deposited in Combustion Chamber, Run No. 8

956 517



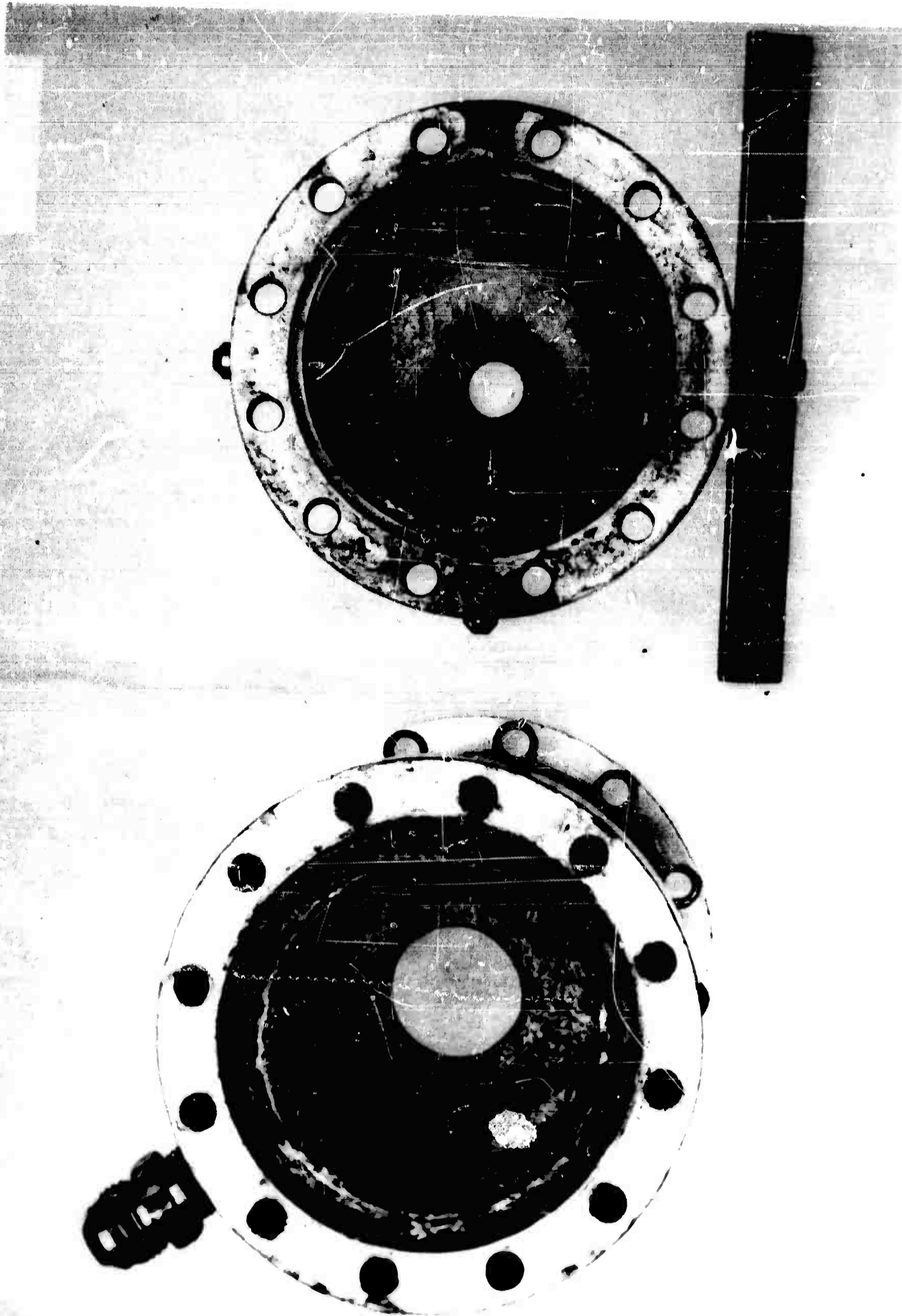
Solids from Untreated Natural Sea Water Deposited on Collector Screens, Run No. 8

956 519



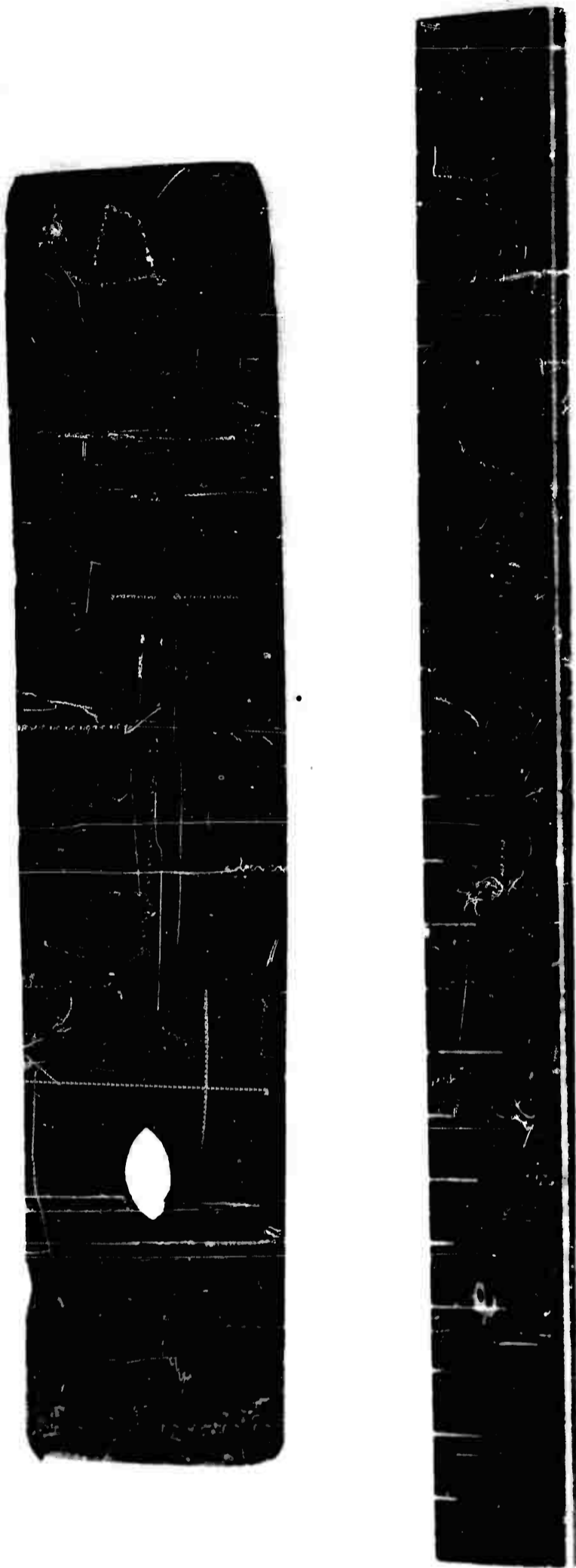
Solids from Untreated Natural Sea Water Deposited on Simulated Turbine Blade, Run No. 8

956 518



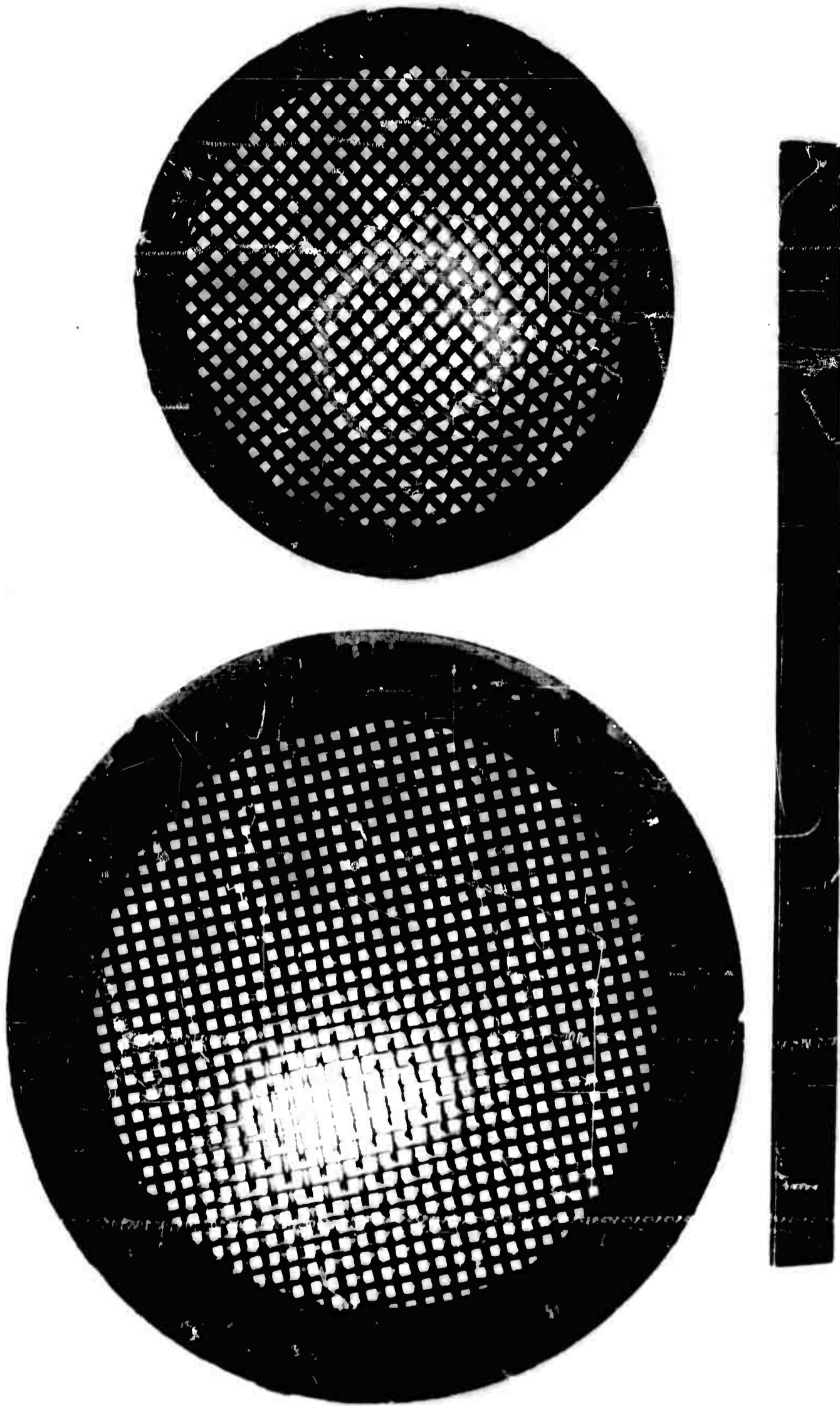
Solids Deposited Inside Combustion Chamber Using Natural Sea Water, Run No. 13

1056-1537



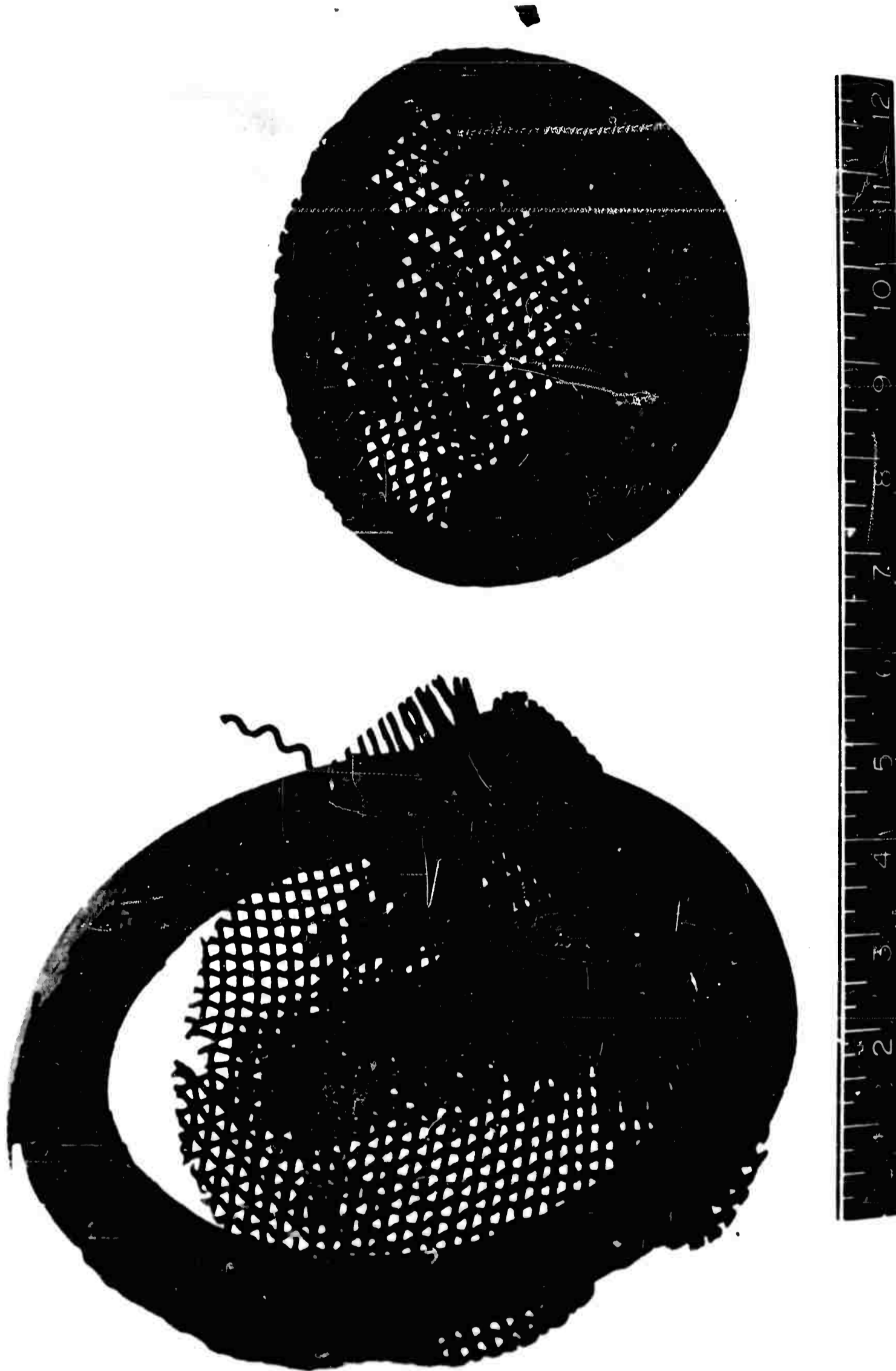
Solids Deposited on Simulated Turbine Blade Using Natural Sea Water, Run No. 13

1056-1533



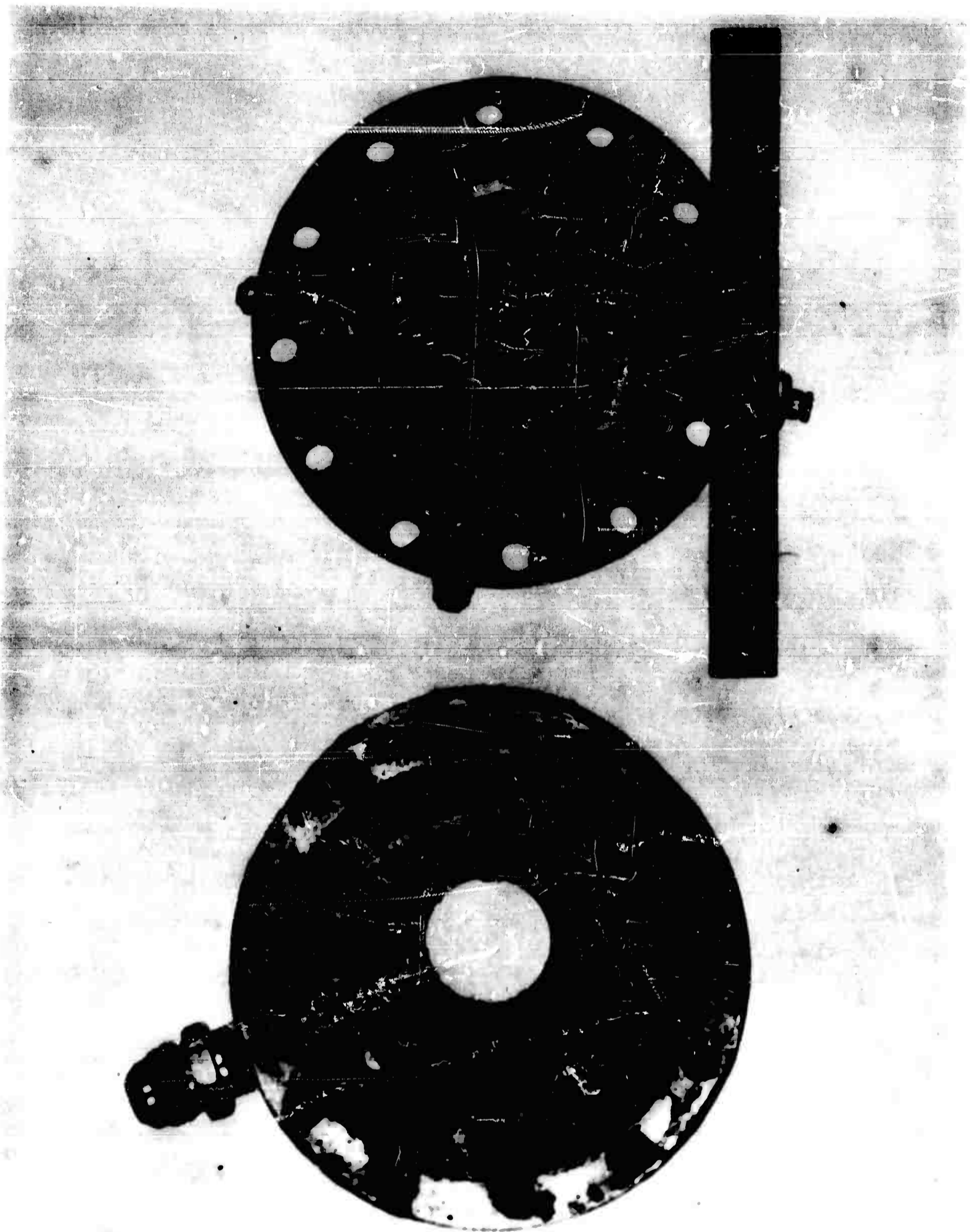
Solids Deposited on Collector Screens Using Natural Sea Water, Run No. 13

1056-1539



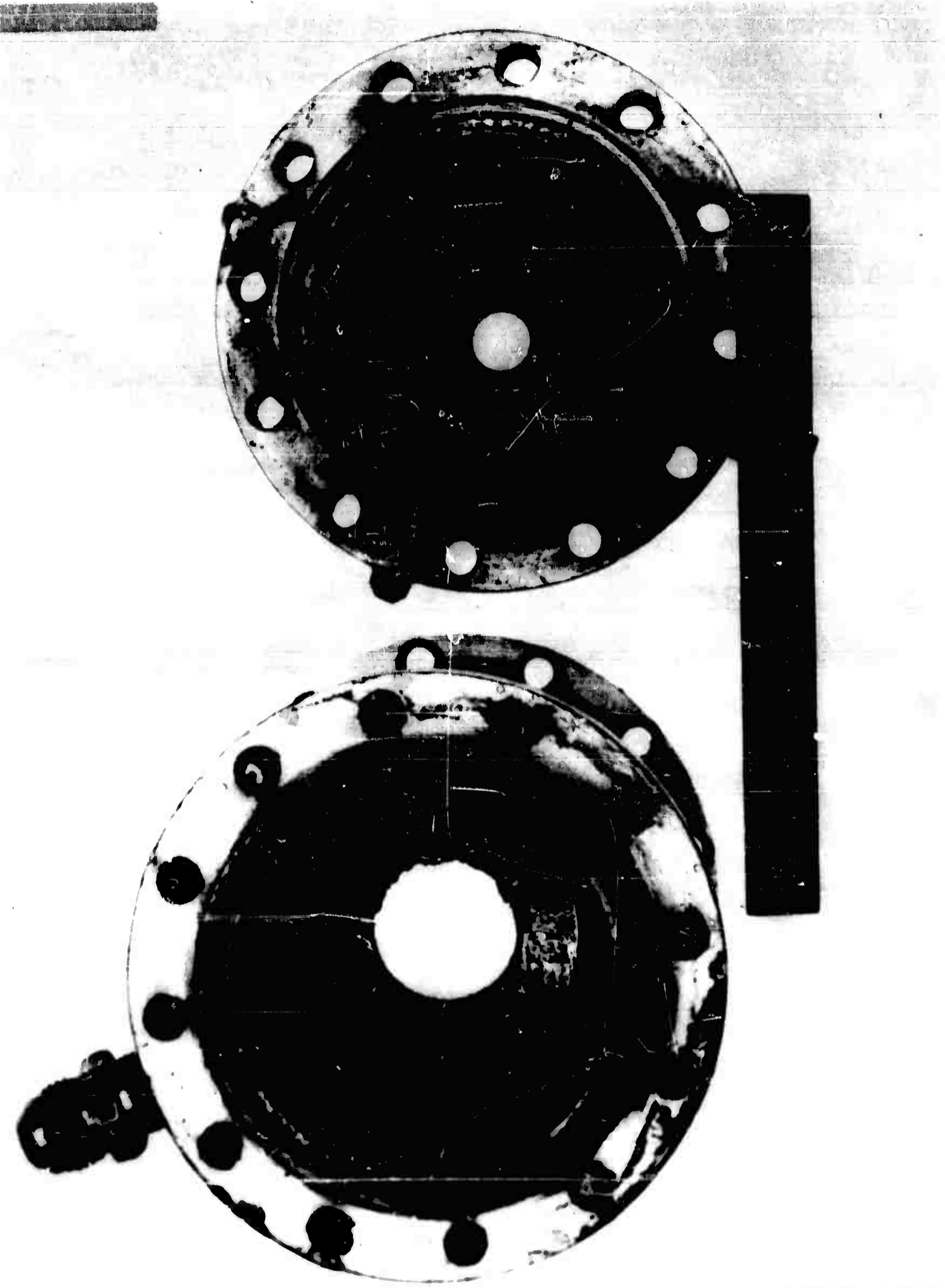
Solids from Treated Sea Water Deposited on Collector Screens, Run No. 7

956 352



357-543

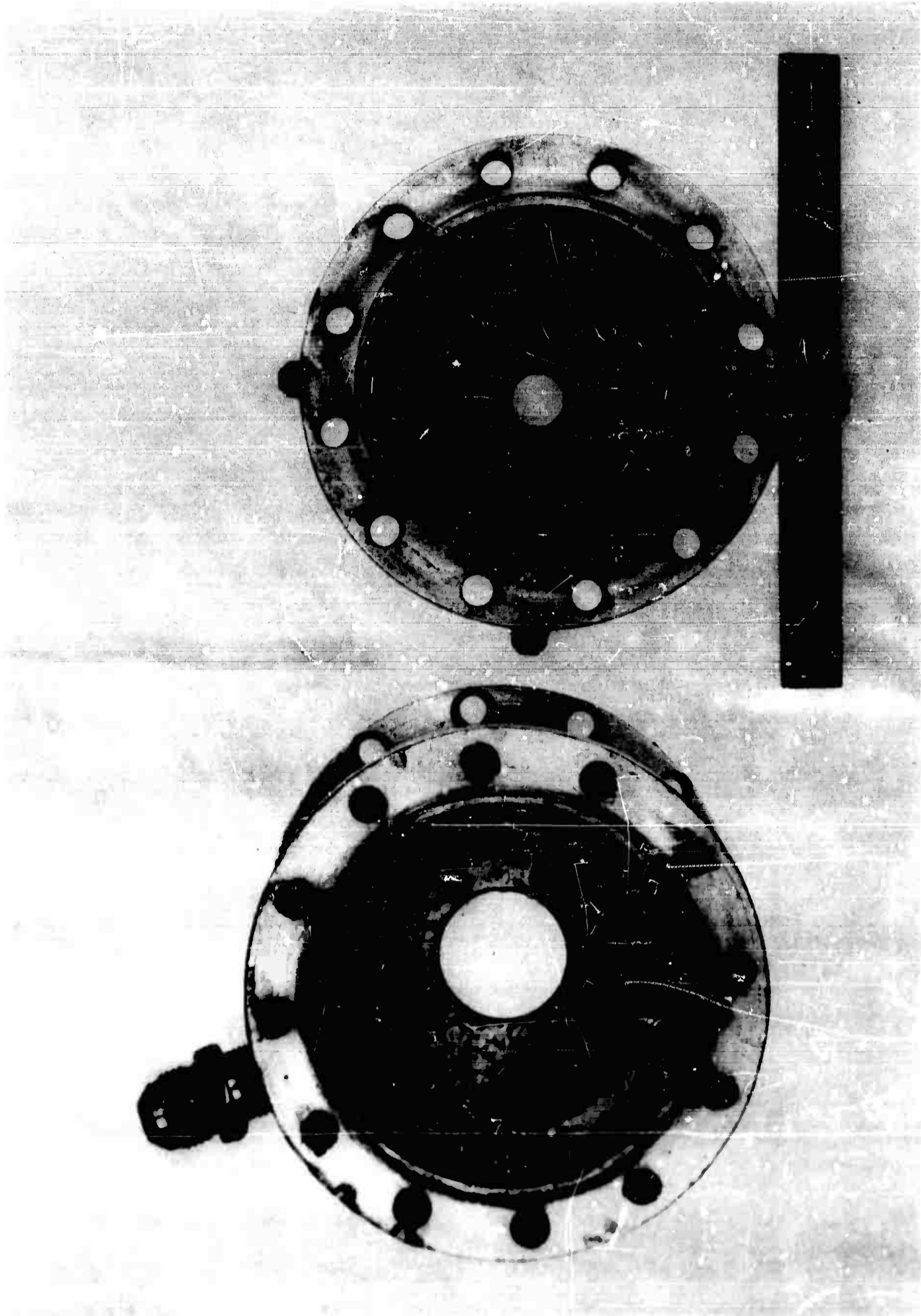
Solids Deposited in Combustion Chamber During Run No. 25



Solids Deposited in Combustion Chamber During Run No. 22

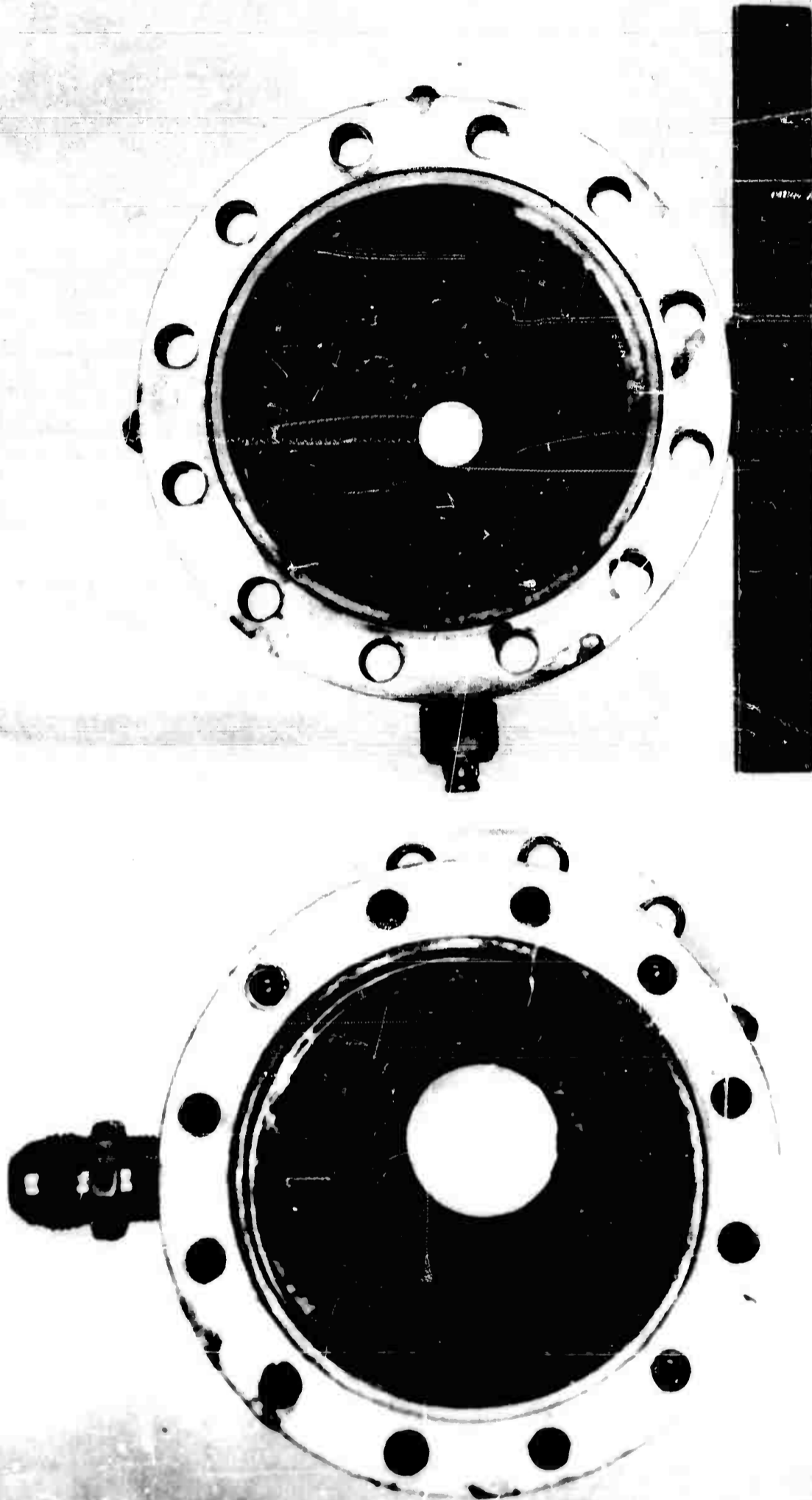
257-619

Figure 70



Solids Deposited in Combustion Chamber During Run No. 19

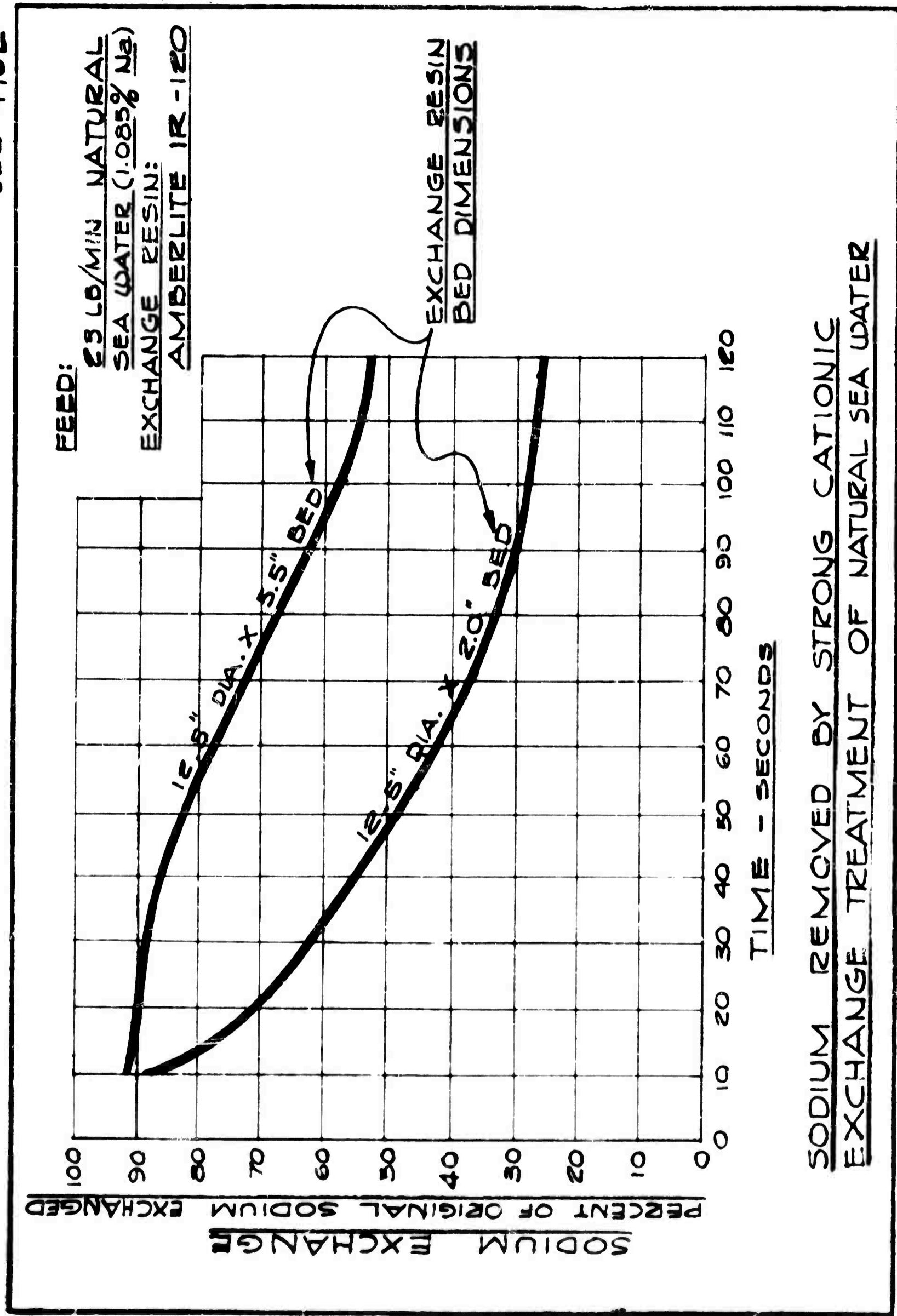
257-257



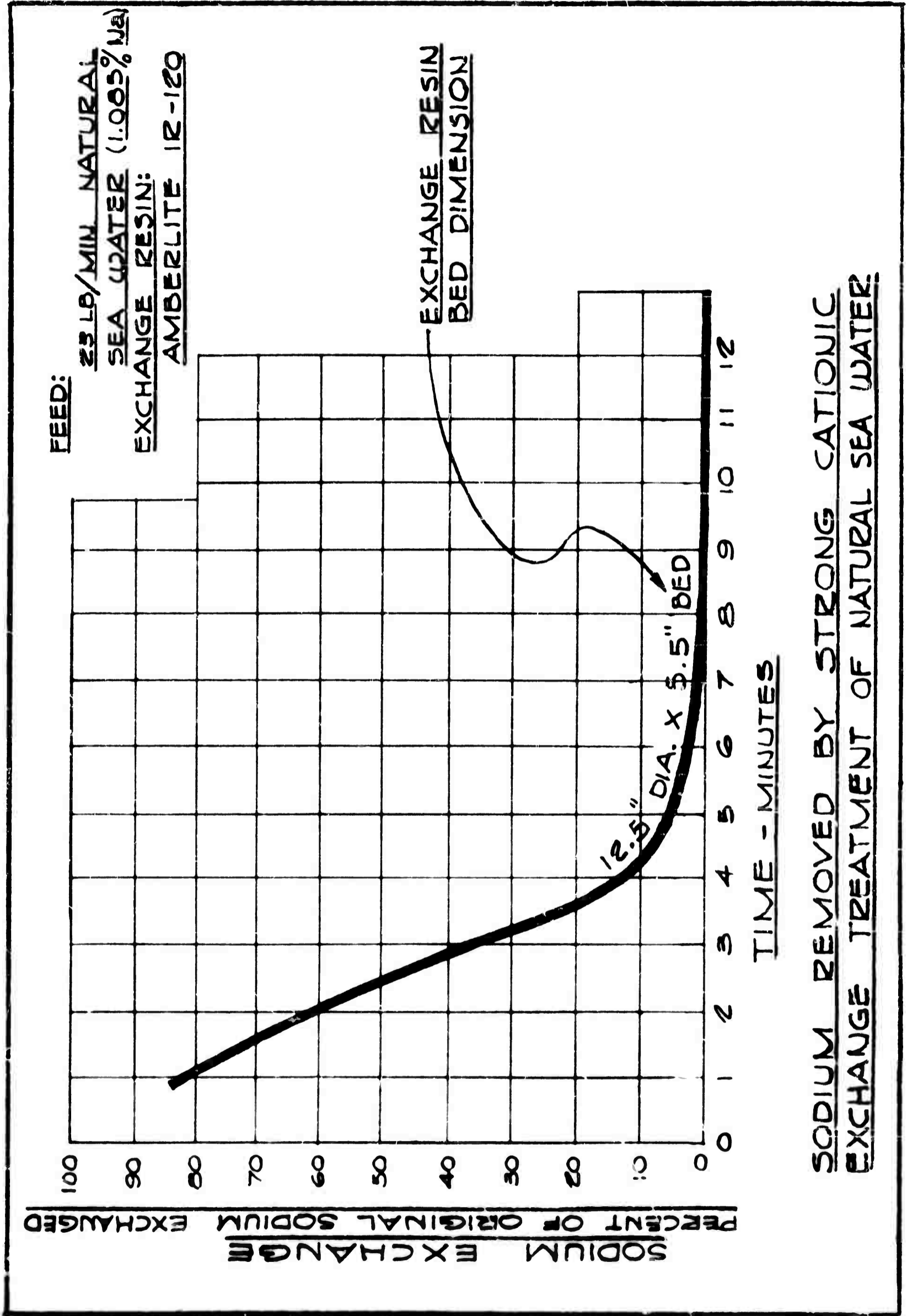
Solids Deposited in Combustion Chamber During Run No. 23

257-727

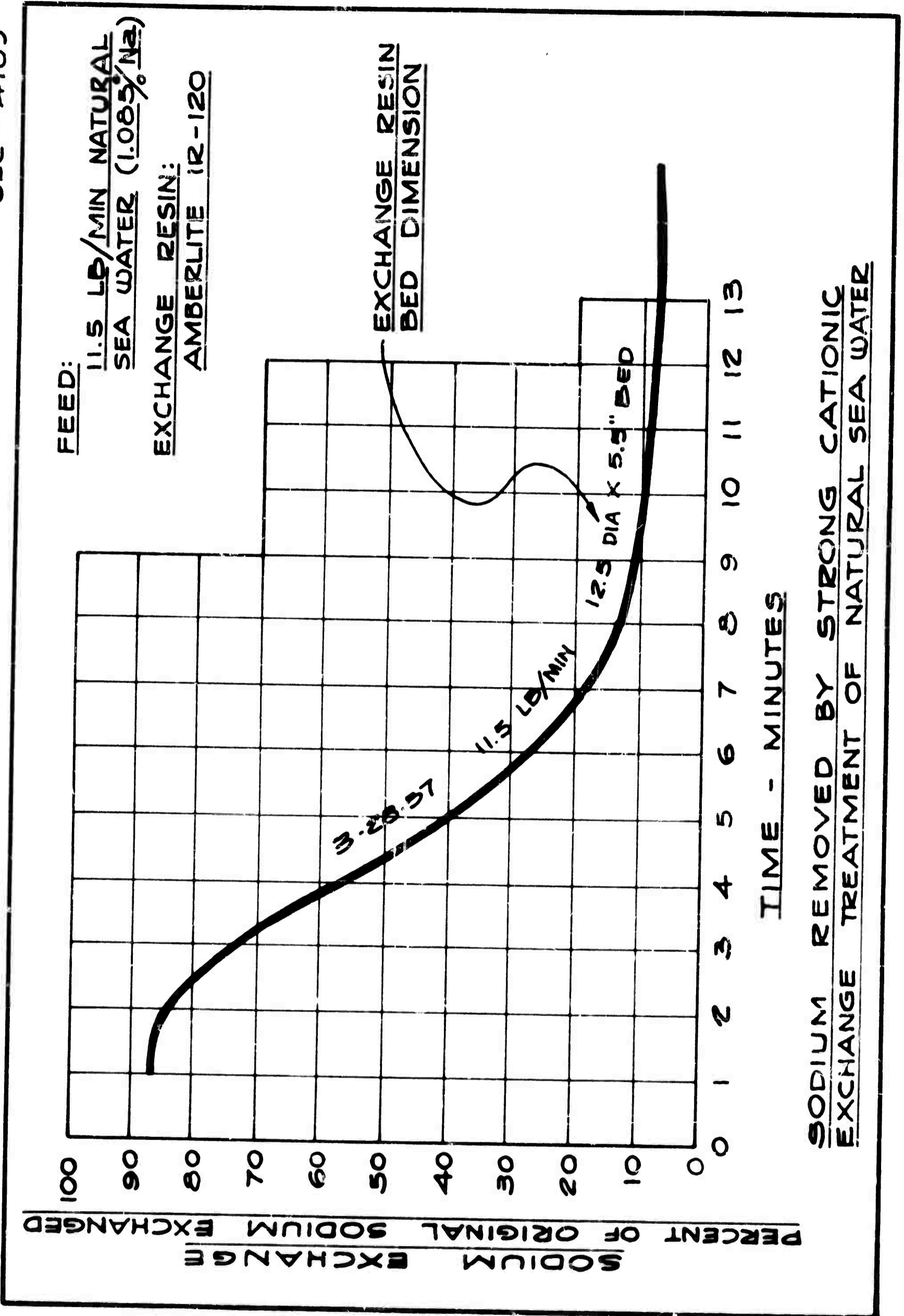
UEC-4702



UEC - 4703



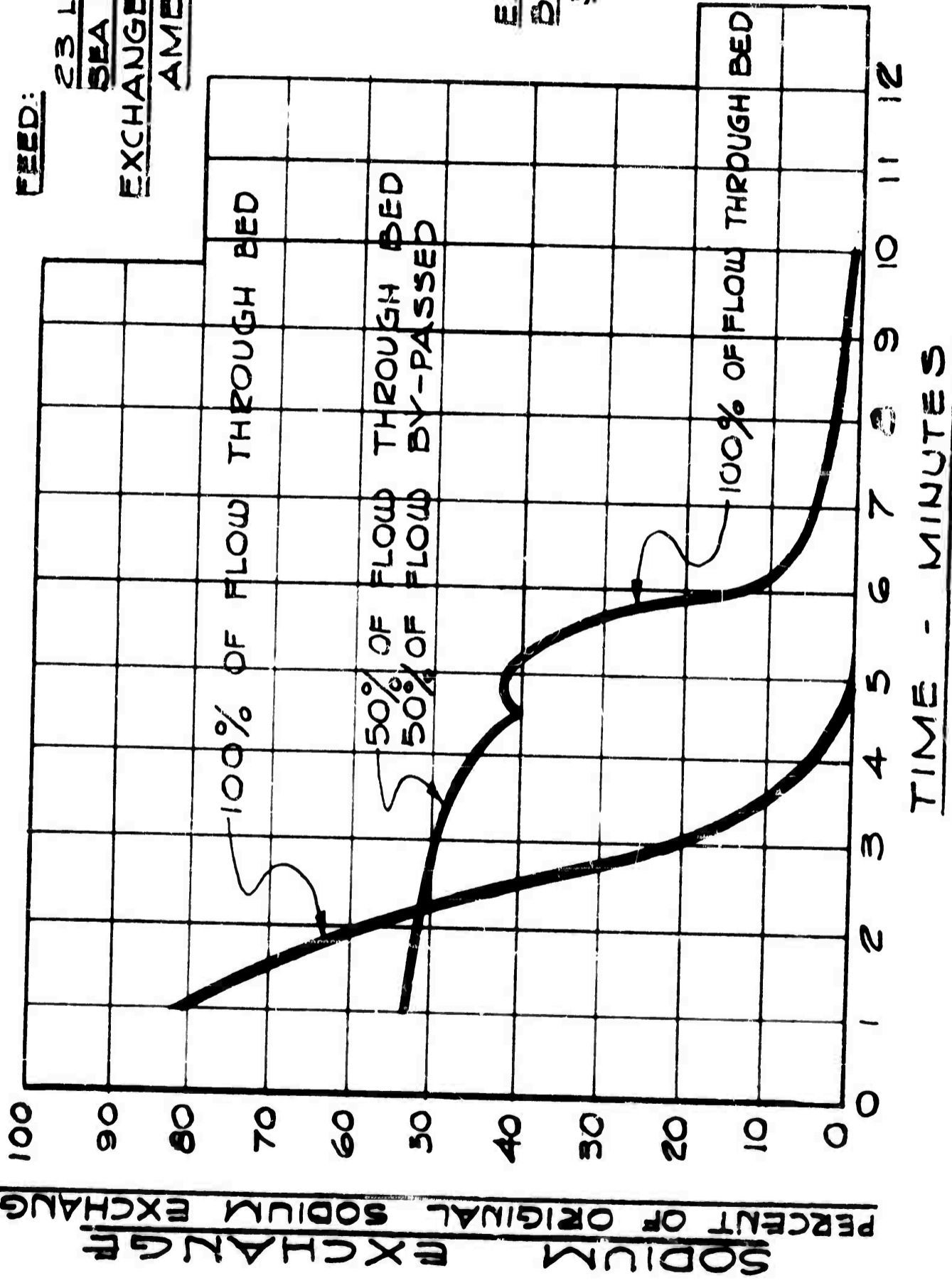
UEC - 4709



DEC 4787

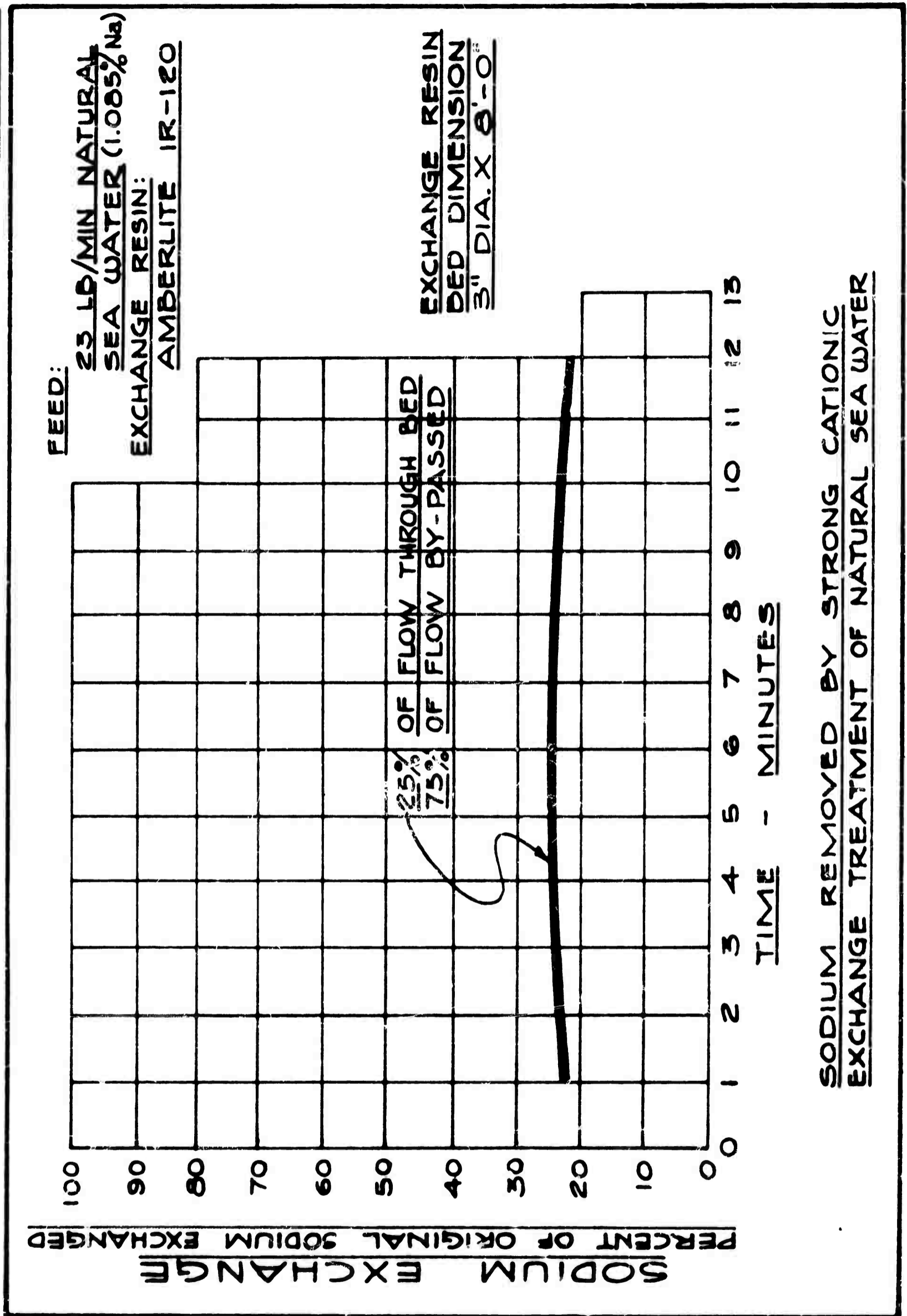
FEED:
23 LB/MIN NATURAL
SEA WATER (1.065% Na)
EXCHANGE RESIN:
AMBERLITE IR-120

EXCHANGE RESIN
BED DIMENSION
3" DIA. X 8'

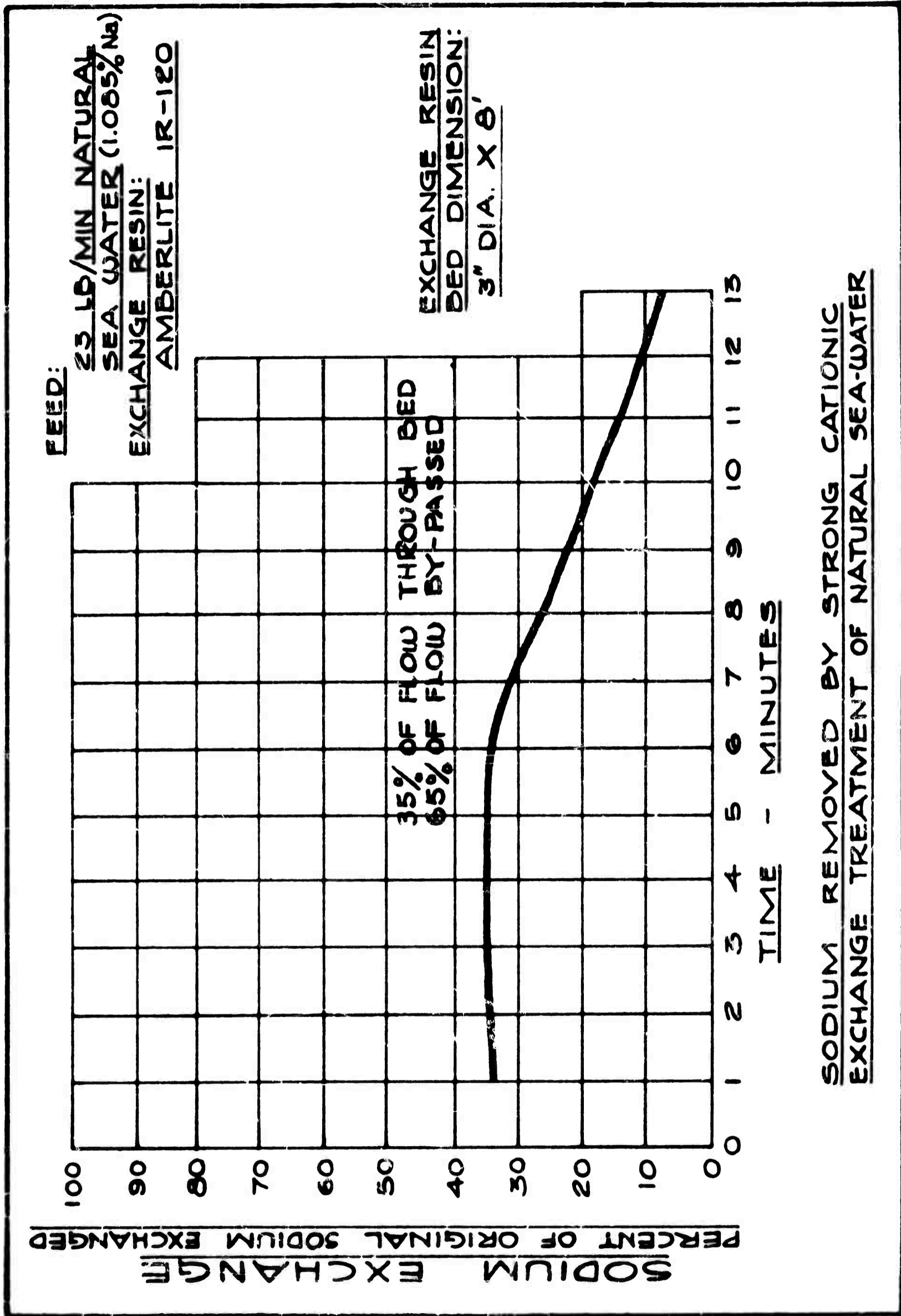


SODIUM REMOVED BY STRONG CATIONIC
EXCHANGE TREATMENT OF NATURAL SEA WATER

UEC 4820



UEC 4844.



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