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QUARTERLY PROGRESS REPORT NO. 3
January 2, 1964 to March 31, 1964

INVESTIGATION OF CAVITATION DAMAGE OF MECHANICAL PUMP IMPELLERS OPERATING IN LIQUID METAL SPACE POWER LOOPS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION

CANEL

MIDDLETOWN CONNECTICUT

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by

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prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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R. S. Kulp and J. V. Altieri

I. SUMMARY

This is the third quarterly report prepared under NASA Contract NAS3-2541 and covers the period from January 2, 1964, to March 31, 1964.

Water testing of the TP-1 turbopump in the PT-4 Water Pump Test Stand was completed during the quarter. The data obtained showed good agreement with the impeller tests conducted in the PT-2 test stand. The five flowrates investigated during the impeller tests (reported in CNLM-5205) were repeated for evaluating cavitation performance of the turbopump. The pump scroll losses were very low and closely approximated the losses of the vaneless diffuser in the previous impeller tests for non-cavitating operation. Scroll effects were more evident in cavitation testing for the higher flowrates at relatively high NPSH (on the order of 35 feet).

Difficulty was experienced in obtaining sound intensity data and recordings similar to those obtained from PT-2 tests because of interference from the pump scroll surrounding the impeller and the generally high sound level in the test stand while the turbine was running. Sound intensity patterns were finally obtained which showed the same trend as the PT-2 test. With decreasing NPSH the sound increased, reaching a peak intensity and then dropping to a minimum, and rising again as the pump head rise fell off at lower values of NPSH.

The results of the TP-1 turbopump water tests were discussed with representatives of the NASA and the conditions set for the 1000-hour, 1400F potassium test in PT-6. These are: a flowrate of 700 gpm, shaft speed of 6375 rpm, and 16.6 feet (including an adjustment of 1.1 feet).* It was also agreed that a limit of three percent drop in head rise is to be observed when establishing cavitating conditions. If the three percent limit occurs before reaching 16.6 feet, the test will be conducted at the corresponding higher value of NPSH.

Orifice-sizing calculations were completed, based on the operating conditions for the liquid metal endurance test. A single orifice was machined and tested in water in the PT-4 test stand. This orifice cavitated violently at the operating point producing severe vibration of the entire test stand. Two orifices in series were found to provide a satisfactory solution to the orifice cavitation problem. One orifice of sufficient diameter not to cavitate will be placed in the originally designated position in the PT-6 test stand. The second orifice will be located close to the pump discharge and about 9 feet upstream of the first orifice.

Construction of the liquid metal test stand (PT-6) was completed during the quarter. The TP-1 was installed and all connections completed. The test loop was evacuated and argon gas admitted to purge-dry the piping. The sump tank was heated to 250F to 300F for complete drying.

II. WATER PUMP TESTS (PT-4)

Hydraulic and cavitation testing of the TP-1 turbopump in the PT-4 test stand were completed during the quarter. The hydraulic performance data obtained are shown in Figure 1 as the solid line. The broken line indicates impeller performance during tests in the PT-2 stand and as reported in the previous quarterly. The increased performance of the turbopump is due to a reduced tip clearance on the impeller over that used in PT-2 tests. The reduced clearance (0.030 inch in PT-4 and 0.035 inch PT-2) was caused by the difficulty of obtaining accurate measurements of the end play of the pump shaft mounted on the deep-groove radial bearing. Since the shapes of the two head-flow curves of Figure 1 are nearly identical, it is inferred that the scroll losses are on the order of those for the vaneless diffuser used in the PT-2 impeller test stand.

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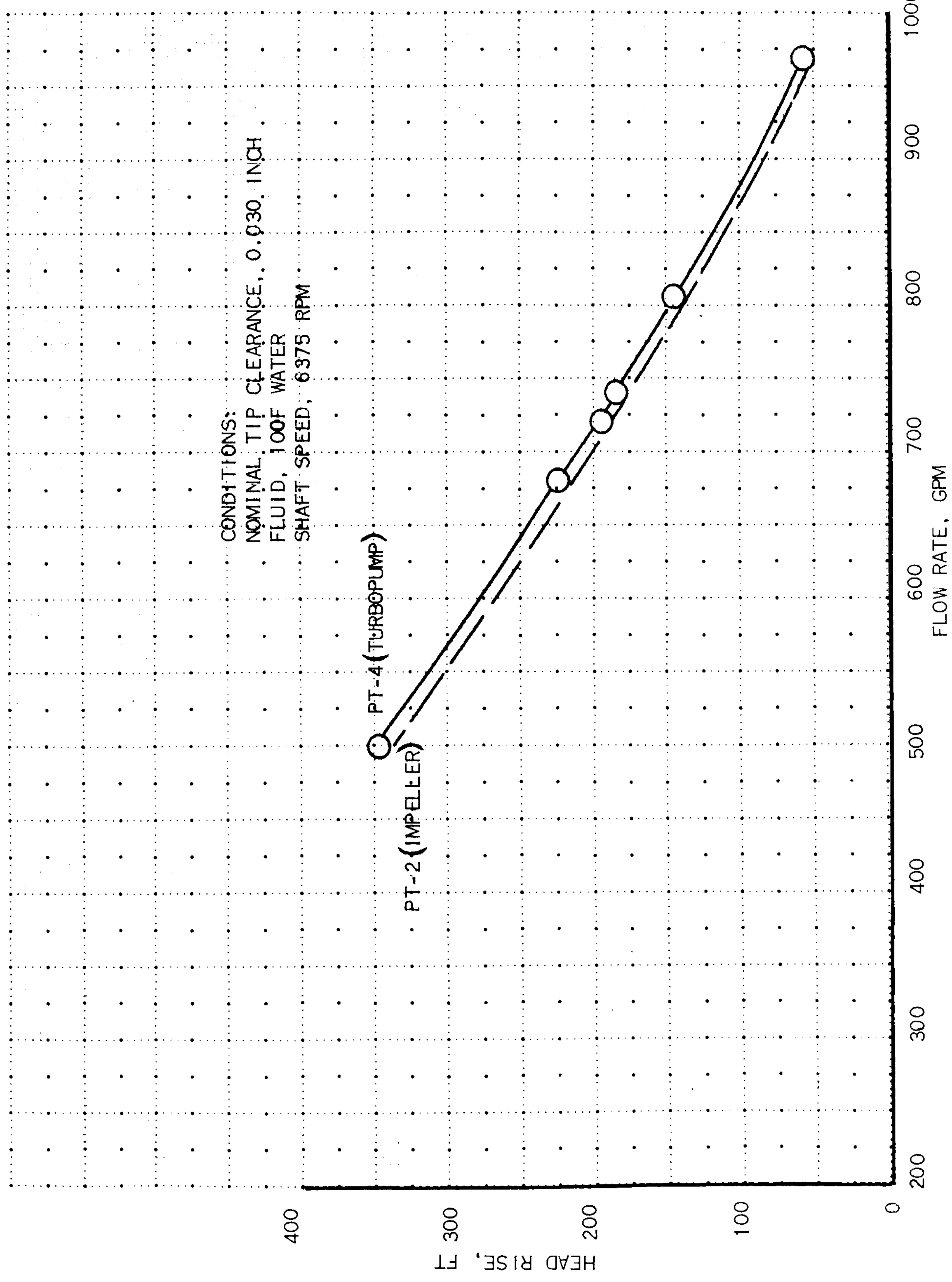
*A. J. Stepanoff, Cavitation Properties of Liquids, ASME Paper No. 63-AHGT-22

FIG 1

HEAD-FLOW FOR THE TP-1 TURBOPUMP WITH THE RI -7C3 IMPELLER



The cavitation performance is shown in Figure 2 for the five flowrates of interest. The performance of this pump is considered to be very good in all respects. The impeller-scroll adapter, which was subjected to considerable analysis, appears not to have adversely affected the performance. Scroll losses at low NPSH were very low for a flowrate of 660 gpm, increasing slightly as flow was increased to 740 gpm.

The cavitation performance of the TP-1 turbopump in PT-4 tests is compared to the performance of the impeller in the PT-2 tests in Figures 3, 4, and 5 for the three flowrates of 660, 700, and 740 gpm. Scroll effects in cavitation performance are evident in these curves. The 660-gpm flow performance in PT-4 tests is very close to that in PT-2 tests as shown in Figure 3. A decrease in head rise begins at higher NPSH for flows of 700 gpm (Figure 4) and 740 gpm (Figure 5) in the PT-4 tests.

Sound intensity data from the PT-4 tests of the turbopump, which would be similar to the PT-2 tests, was difficult to obtain. The position of the pump scroll in relation to the impeller provided a longer transmission path through water and steel. This caused a greater attenuation of the transmitted sound than occurred in the PT-2 tests. Coupling effects between different materials is considered to have contributed to the attenuation. The sound transmission path in PT-2 was from water to plastic to air, involving only two interfaces of different material. In the PT-4 test, the transmission path was from water to stainless steel to an adjacent stainless steel part to water to stainless steel to air. This produced five material interfaces where coupling effects could possibly reduce transmitted sound.

The general sound level in the PT-4 test stand was higher than for the PT-2 tests as a result of the turbine operation. Sound intensity data similar to the PT-2 tests was finally obtained by wrapping the turbine scroll and pump scroll with a sound-absorbing thermal insulation. The sound level meter was fitted with a cardboard tube over the microphone which was directed at the inlet pipe immediately below the pump scroll. This position provided the shortest sound transmission path through water and steel. The cardboard tube acted as a sound wave director to the microphone. The complete setup for obtaining sound data is shown in Figure 6. This same arrangement will be used in the liquid metal tests of PT-6 with a copper tube wrapped with a sound-absorbing insulation replacing the cardboard tube.

The sound intensity data are shown in Figures 3, 4, and 5 above the cavitation performance curves. The shape of these sound curves is similar to that obtained during the impeller tests in the PT-2 test stand. The sound curve for 700 gpm from PT-2 tests is plotted in Figure 4 as a broken line for comparison. It is apparent from this comparison that the background sound intensity from the turbopump water test was considerably greater than for the impeller test.

Figure 7 is a cross-plot of the sound intensity data showing the topographical pattern of sound generated over the five flowrates.

III. ORIFICE CALIBRATION

The data covered in the preceding section were discussed with representatives of the NASA on January 23, 1964, at the Lewis Research Center, Cleveland, Ohio. At that time, it was agreed that the following conditions will be set for the 1400F potassium test: 1) shaft speed: 6375 ± 20 rpm, 2) flow: 700 ± 20 gpm, 3) head rise is not to drop more than three percent of the maximum head rise or a minimum NPSH of 16.6 feet, whichever occurs first. It should be noted that the selected NPSH value of 16.6 feet contains an NPSH adjustment of 1.1 feet based on the thermal properties of the liquid. This adjustment is discussed in an ASME paper (No. 63-AHGT-22) entitled, "Cavitation Properties of Liquids," by Dr. A. J. Stepanoff.

Orifice size calculations were completed using the endurance point previously stated. An orifice was machined to the size calculated and installed in the PT-4 test stand in the position shown in Figure 30 of CNLM-5205 (Quarterly Progress Report No. 2). The pressure conditions expected in PT-6 operation were then set around this orifice and flow readings taken. As the flow approached 700 gpm, the orifice began cavitating, and at 700 gpm was cavitating so violently that the turbopump was experiencing severe vibrations. Deflections of greater than 5 mils were detected.

FIG 2

CAVITATION PERFORMANCE OF THE TP-1 TURBOPUMP WITH THE RI-7C3 IMPELLER

CONDITIONS:
NOMINAL TIP CLEARANCE, 0.030 INCH
FLUID, 100F WATER
SHAFT SPEED, 6375 RPM

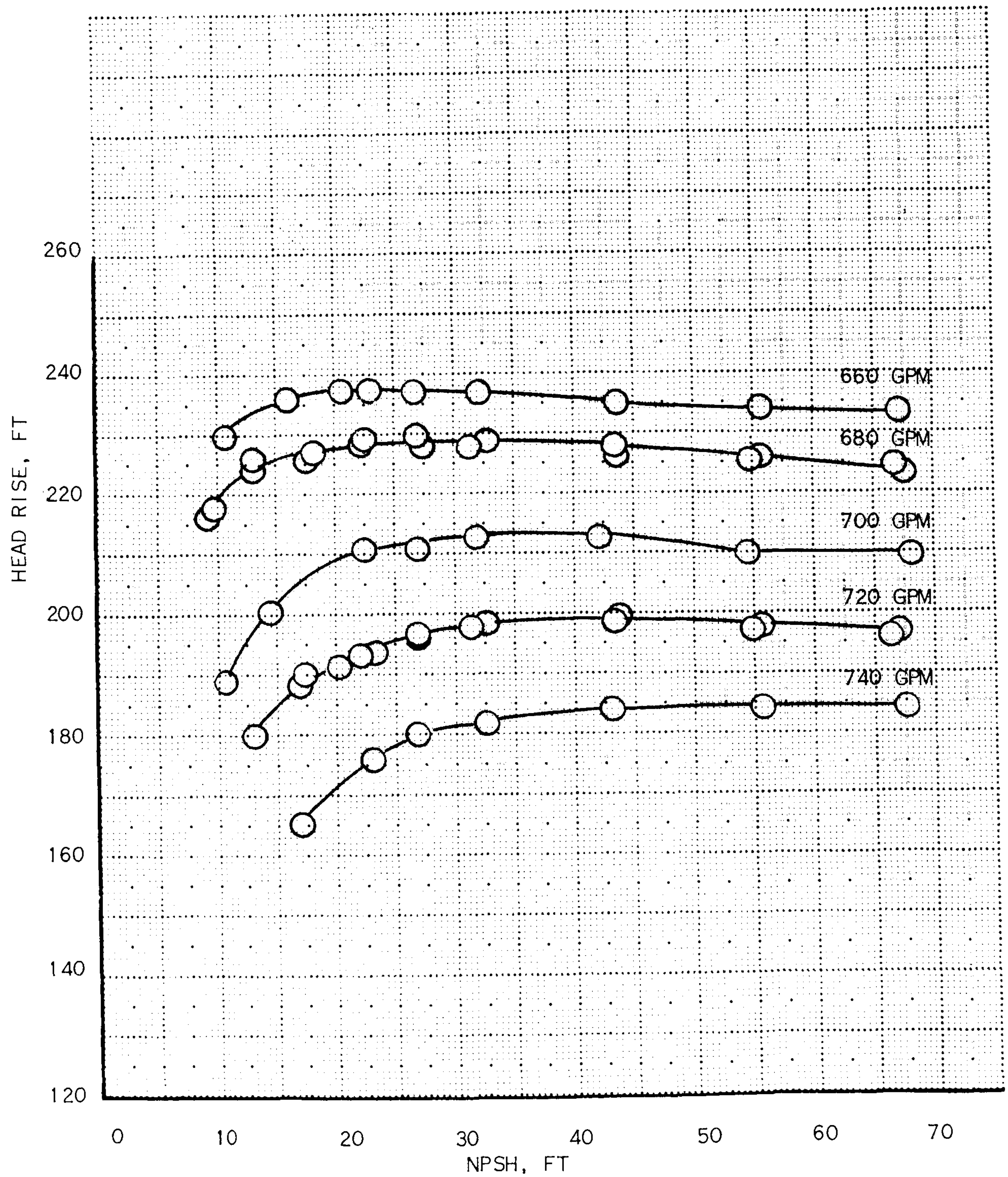


FIG 3

NOISE AND HEAD RISE VERSUS NPSH FOR THE TP-1 TURBOPUMP WITH THE RI-7C3 IMPELLER AT 660 GPM

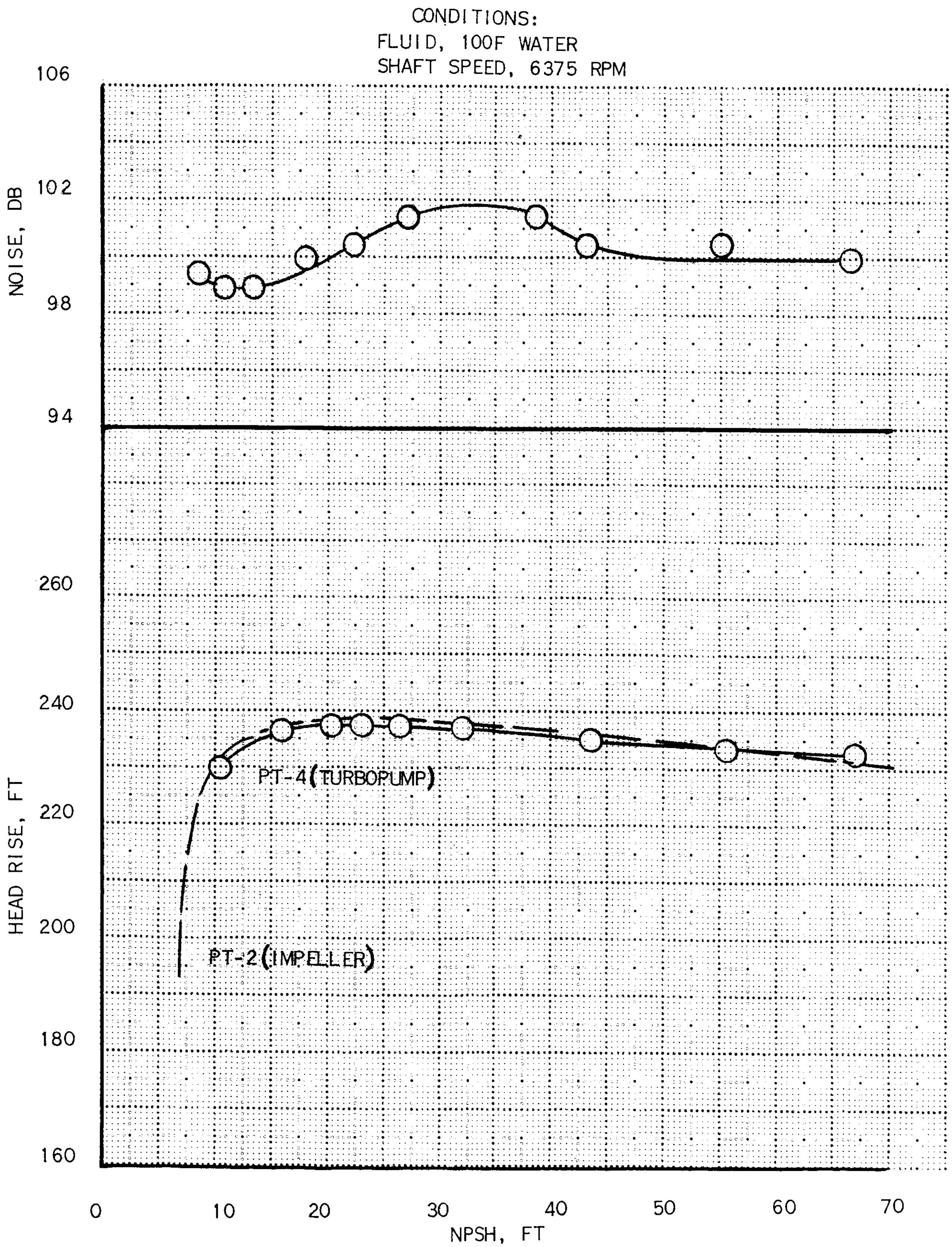


FIG 4

NOISE AND HEAD RISE VERSUS NPSH FOR THE TP-1 TURBOPUMP WITH THE RI-7C3 IMPELLER AT 700 GPM

CONDITIONS:
FLUID, 100F WATER
SHAFT SPEED, 6375 RPM

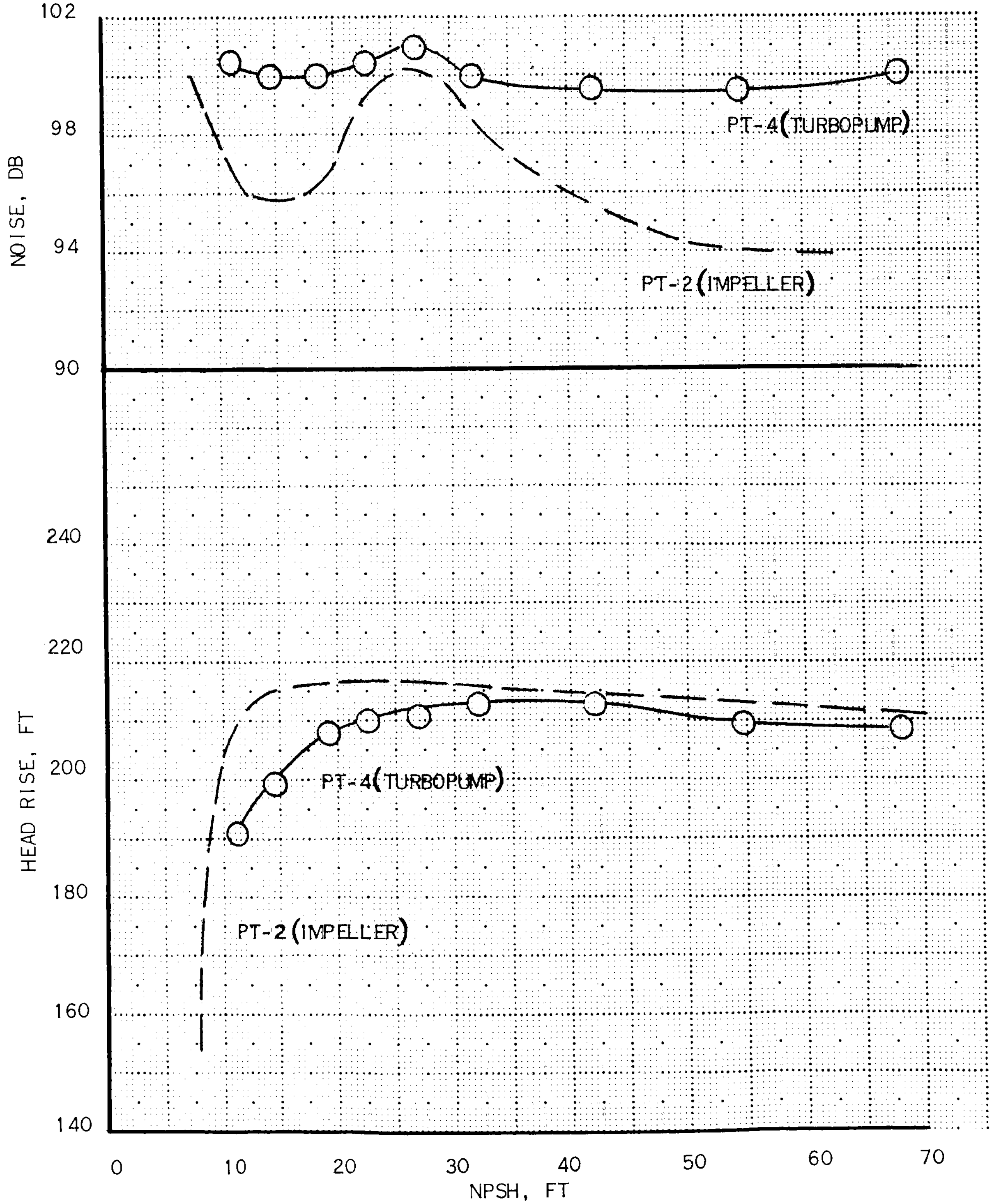


FIG 5

NOISE AND HEAD RISE VERSUS NPSH FOR THE TP-1 TURBOPUMP WITH THE RI-7C3 IMPELLER AT 740 GPM

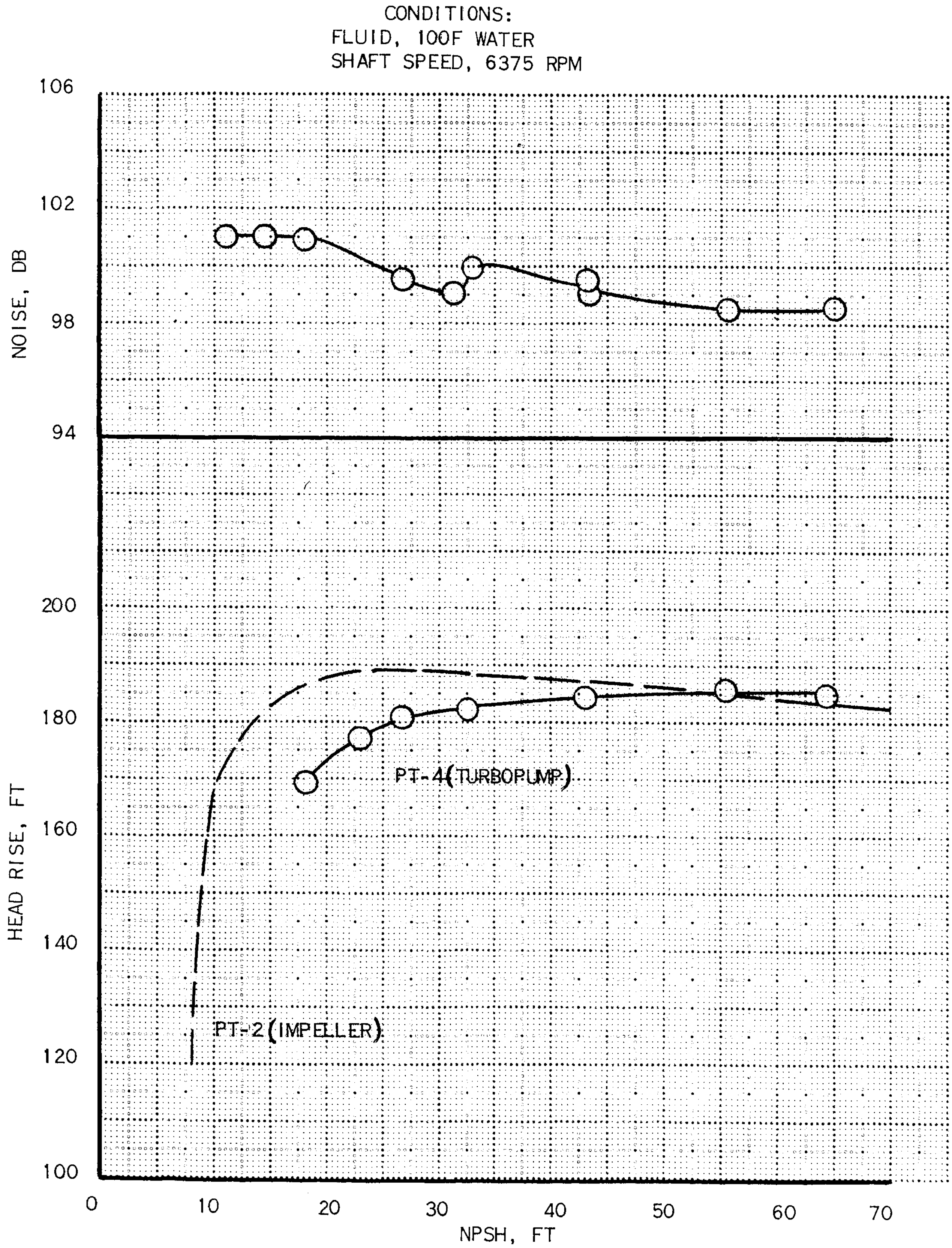


FIG 6

SETUP FOR SOUND READINGS IN PT-4 TEST STAND

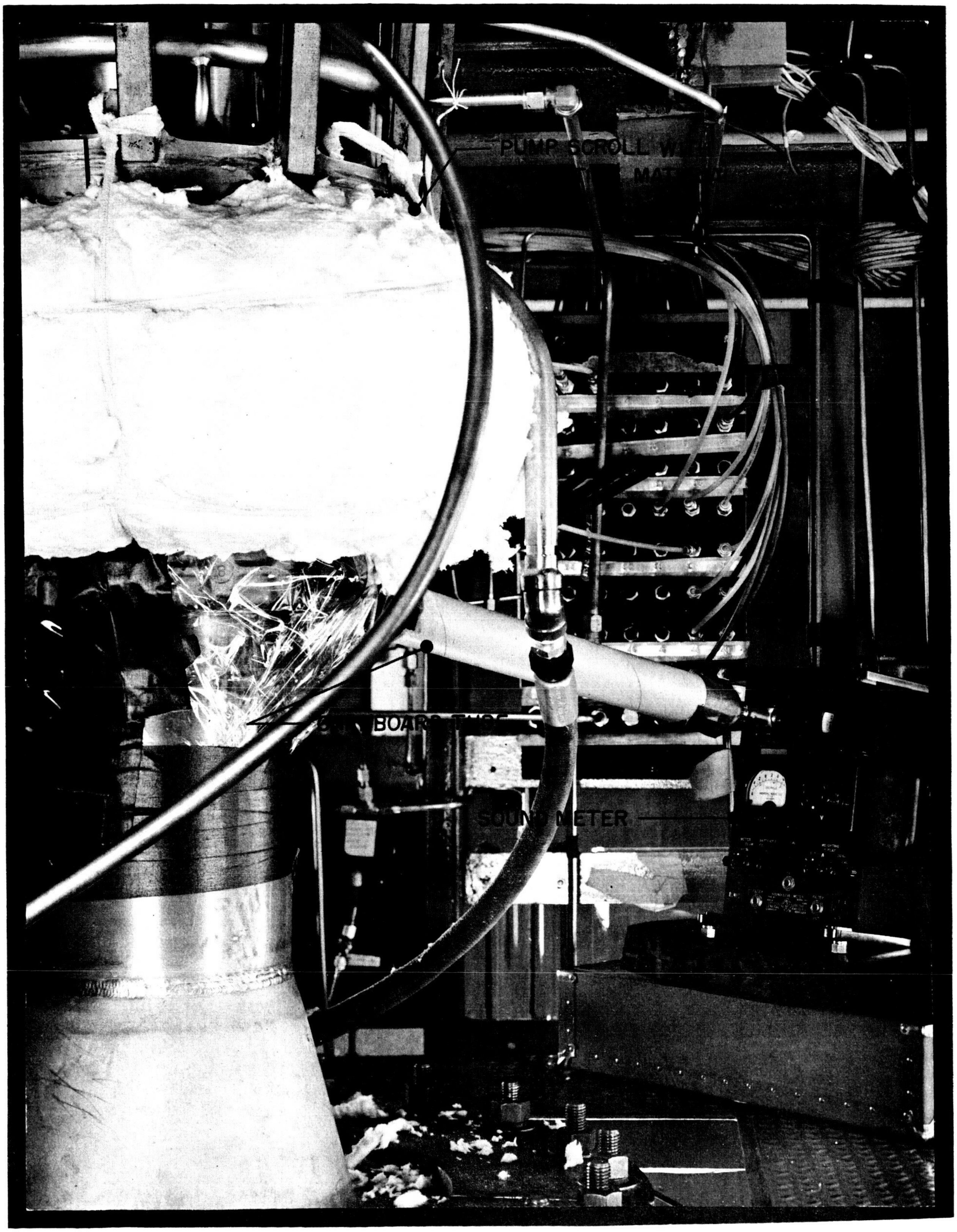
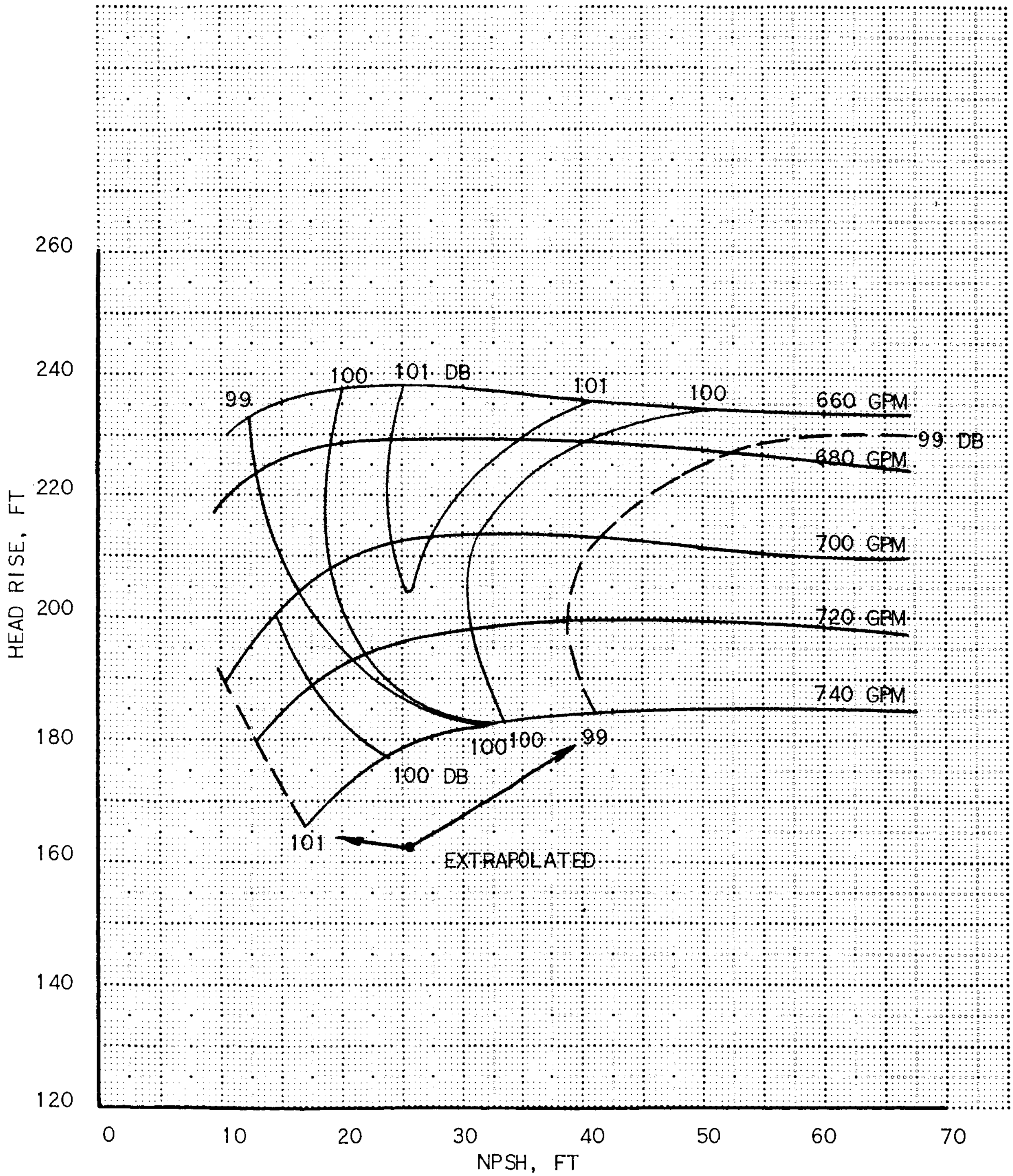


FIG 7

CROSS PLOT OF NOISE AND CAVITATION PERFORMANCE FOR THE TP-1 TURBOPUMP

CONDITIONS:
NOMINAL TIP CLEARANCE, 0.030 INCH
FLUID, 100F WATER
SHAFT SPEED, 6375 RPM



It was resolved that two orifices be used in series, one located at the the elbow position and one about 14 inches from the pump discharge. This would allow a separation of approximately nine feet between the orifices. The orifice diameter of 2.500 inches was selected for the elbow position which, from previous testing, was known not to cavitate at 700 gpm flow. The second orifice diameter was calculated to be 2.100 inches. The configuration of the PT-4 water test loop would not allow a test of both orifices in series. The 2.5 inch orifice was positioned in PT-4 and pressure and flow measurements taken. These measurements were then used to calculate the second orifice diameter, which is 2.1 inches . This orifice was then placed in the loop and pressures set up downstream to simulate the measured inlet pressures to the 2.5-inch diameter orifice, taking into account the pressure drop introduced by the elbow. Upstream measurements were then taken at the desired flow of 700 gpm and checked against calculated values. At the 700 gpm flow, both orifices checked calculated pressures within 0.4 psi or 0.5 percent of the total pressure drop required. The 2.5-inch diameter orifice is shown in Figure 8 installed in the PT-6 loop piping. A non-condensable gas vent and liquid metal drain hole were cut on the periphery of the orifice plates, as shown in the photograph. The photograph is blurred slightly from camera movement which was not detected at the time the photograph was taken.

IV. PUMP DISASSEMBLY AND IMPELLER INSPECTION

The TP-1 turbopump was removed from PT-4 test stand at the completion of the orifice calibrations. The pump was partially disassembled and inspected for unusual seal wear or any indications of impending trouble. It was noted at this time that the impeller had rubbed lightly against the scroll adapter at some time during the PT-4 tests. Figures 9 and 10 are photographs of the scroll adapter and impeller showing the rub marks.

In neither case do the rub marks go completely around either part. This would indicate that rubbing contact was made during a synchronous transient condition. It is considered likely that the rubbing contact occurred during the period of severe vibration that existed when the originally calculated orifice was being tested. The upper portion of the turbopump was rigidly fixed to the air supply line and exhaust which allowed the pump shaft and housing to deflect under the imposed loads. The wear marks were smoothed off, but not entirely eliminated, by hand-working.

The impeller was given detailed inspection to determine its condition prior to the potassium test. The inspection procedure included surface roughness measurements dye penetrant, X-ray, and photographic methods. Weight measurements were also made.

Surface roughness measurements indicated that a very slight smoothening effect had occurred on the pressure side of the impeller blades. This is shown in Figure 11 by the reduced number of small jagged peaks on the lower trace. No smoothening was found on the suction surface of the blades. This was verified further by the fact that dye penetrant inspection did not show the indications as reported in Quarterly Progress Report No. 1 (CNLM-5202, Figure 12). These indications were near the root on the pressure side of blade three. Current dye penetrant inspection showed no indications which could be photographed; therefore, no photographs were taken. X-ray inspection revealed no internal cracks or change of internal structure. Photographs of the available blade surfaces were taken at twice and four times magnification. Weight measurements indicated a loss of weight of approximately one-half gram. This is more probably due to the material removed during rubbing contact.

V. PUMP ASSEMBLY

Reassembly of the turbopump after the inspections was accomplished without difficulty. The oil seals were relapped to provide effective sealing.

The impeller tip clearance was set cold at approximately 0.017 inch in order to account for the thermal growth. This value of tip clearance was based on actual measurements of other similar high temperature liquid metal pumps and on thermal caluclations. The pump housing will expand more than the pump shaft during high temperature operation due to the cooling effect of the sweep gas flow down along the shaft. The resulting clearance at 1400F is estimated as 0.032 inch.

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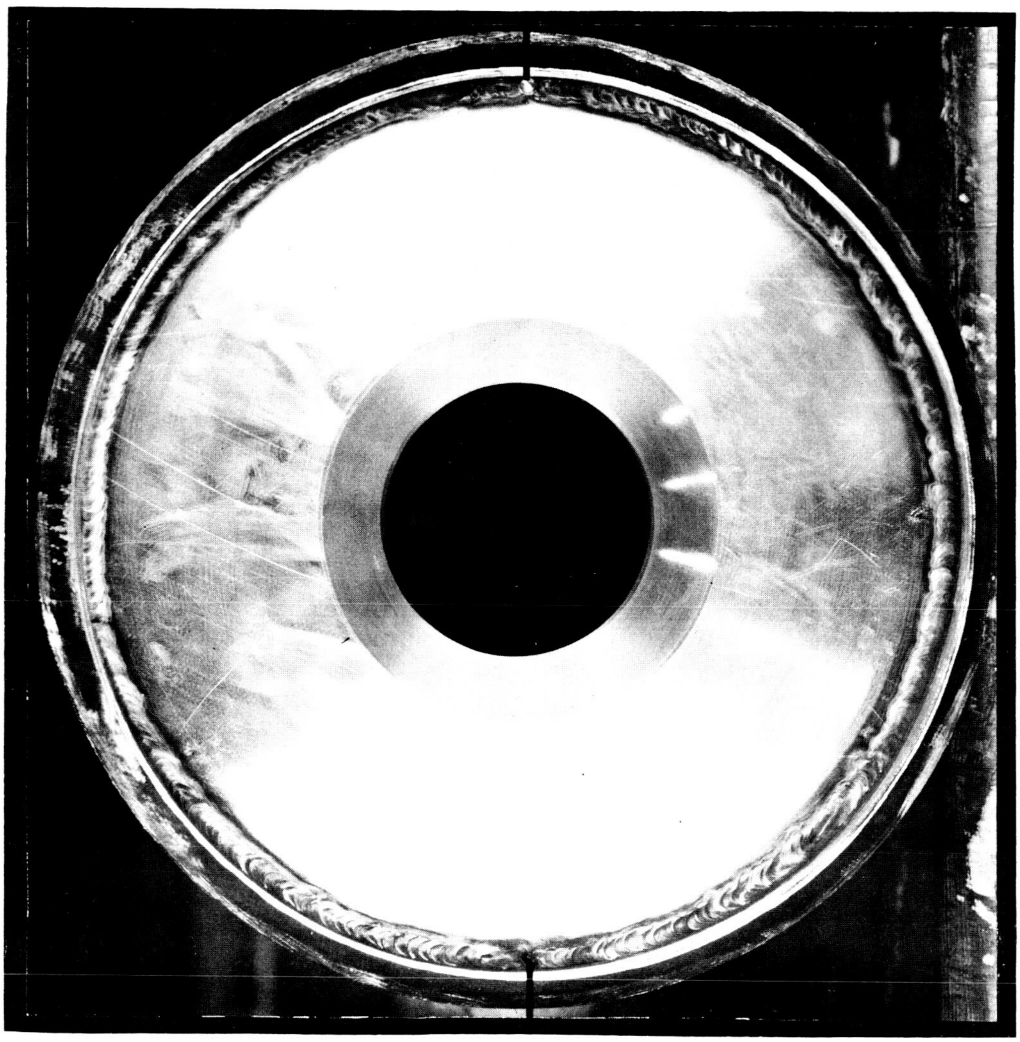
FIG 8

2.5 INCH DIAMETER ORIFICE INSTALLED IN PT-6 LOOP PIPING

GAS VENT



LIQUID METAL
DRAIN

FIG 9

OVERALL VIEW OF LOCALIZED SCORING ON IMPELLER

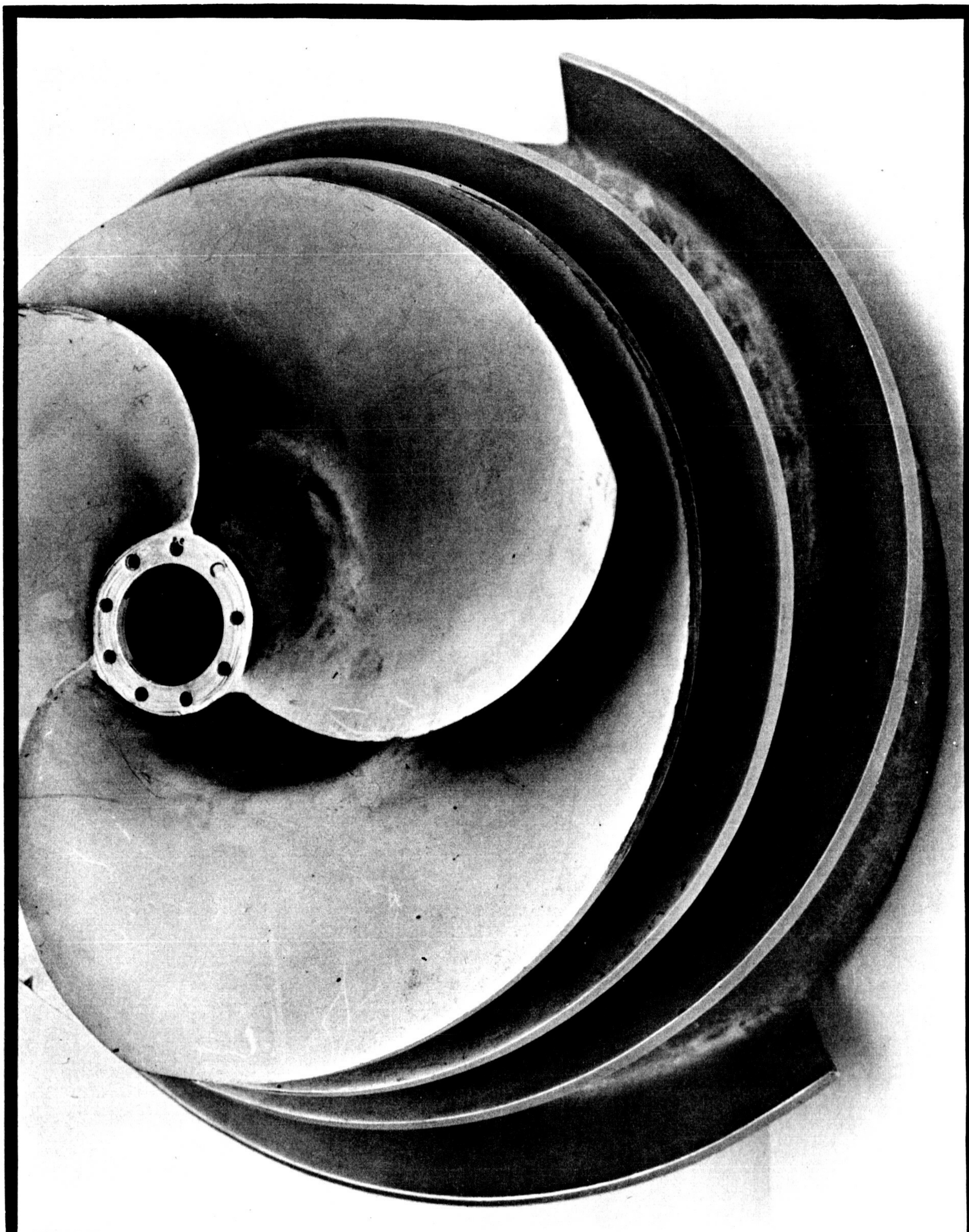


FIG 10

IMPELLER RUB MARKS IN PUMP SCROLL AFTER TEST IN PT-4 STAND

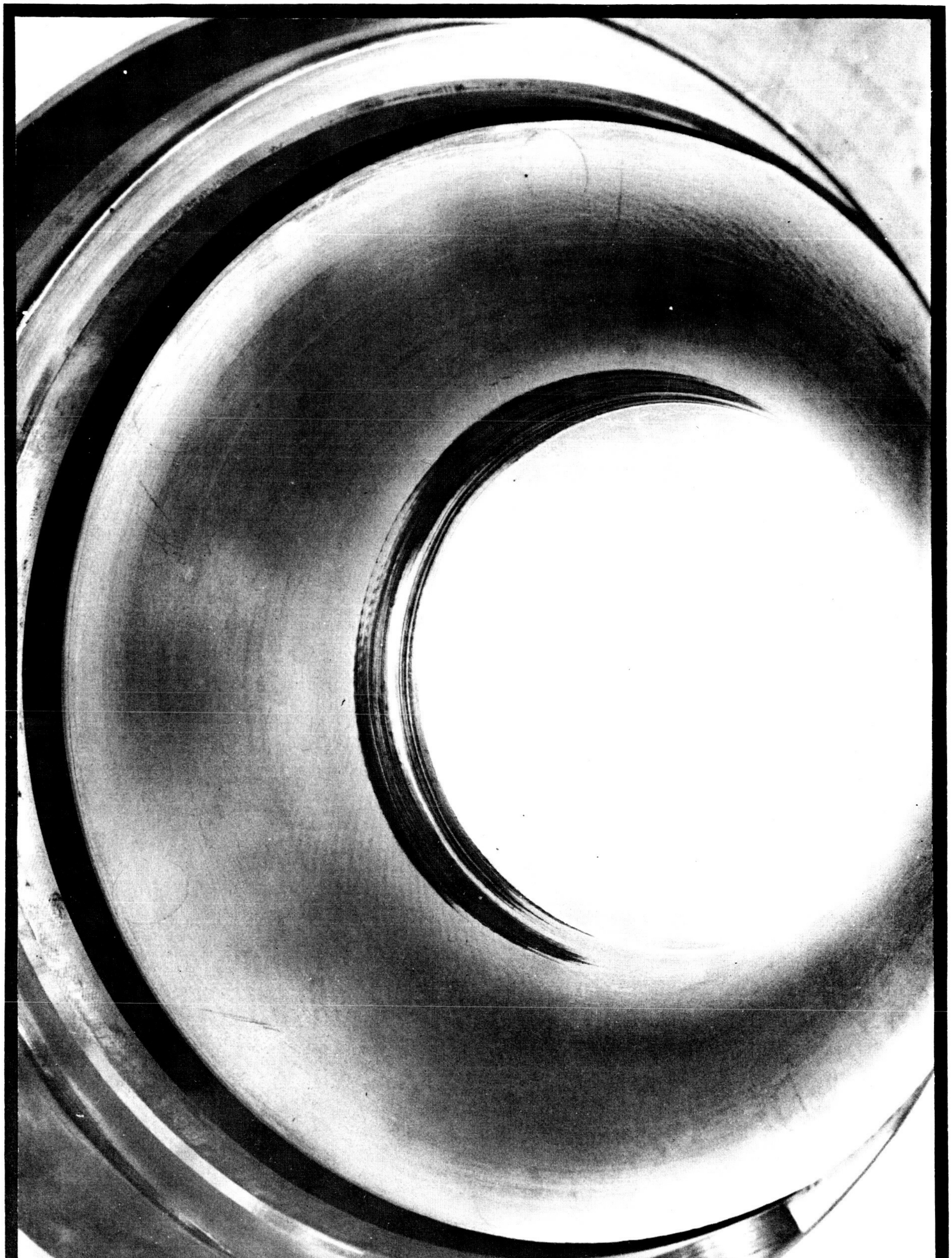
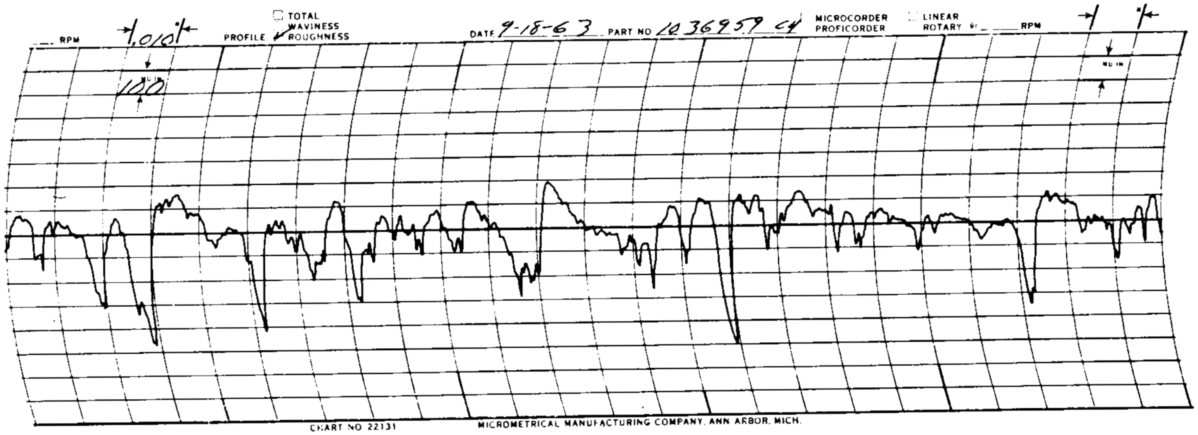


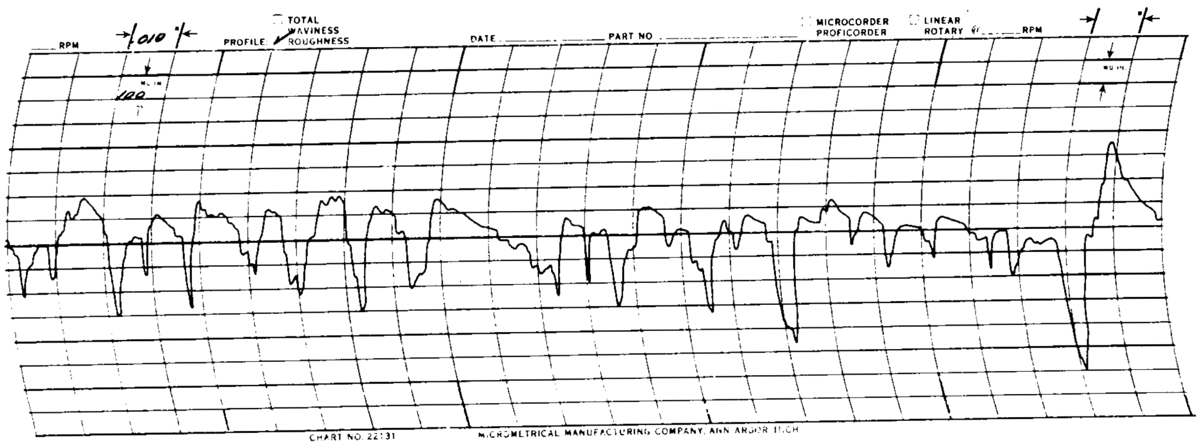
FIG 11

SURFACE ROUGHNESS MEASUREMENTS

BLADE 2, STATION 6, PRESSURE SIDE



BEFORE WATER TEST



AFTER WATER TEST

VI. LIQUID METAL STAND (PT-6) CONSTRUCTION

The liquid metal test stand (PT-6) construction was completed this quarter. A photograph showing the completed stand is given in Figure 12. A closeup view of the installed pump is presented in Figure 13. Preliminary cleanup operations are in progress. These include evacuation of the test loop and backfilling with argon gas, heating of the loop, and purging with purified argon to remove water vapor and residual oxygen. Purification of the potassium has been completed. Final oxygen level was obtained by the mercury amalgam method with three samples having readings of 16, 16, and 18 ppm.

The TP-1 turbopump was dry-run to check turbine controls and verify satisfactory operation of the cermet shaft face seals.

VII. WORK TO BE PERFORMED DURING THE NEXT QUARTER

Work to be performed during the next quarter will include final loop cleanup, system shakedown, the 1000-hour endurance test, and impeller examination. The cleanup of the loop will be done in two steps. First, a NaK flush of the dump tank will be made without filling the test loop. Secondly, the system will be charged with potassium and circulated at temperatures up to 1200F. This will allow preliminary checks to be made of orifice sizes and system controls. Oxygen level of the potassium will be closely monitored.

The system shakedown run will include data recording of non-cavitating head rise, cavitating performance at the flowrate established by the orifice, and sound intensity during cavitating performance.

Inspection of the impeller after the endurance test will be completed. Inspection methods include surface roughness measurement, X-ray, dye penetrant, photographic and over-all weight change. Metallographic and chemical examinations will be completed.

FIG 12

LIQUID METAL TEST STAND, PT-6

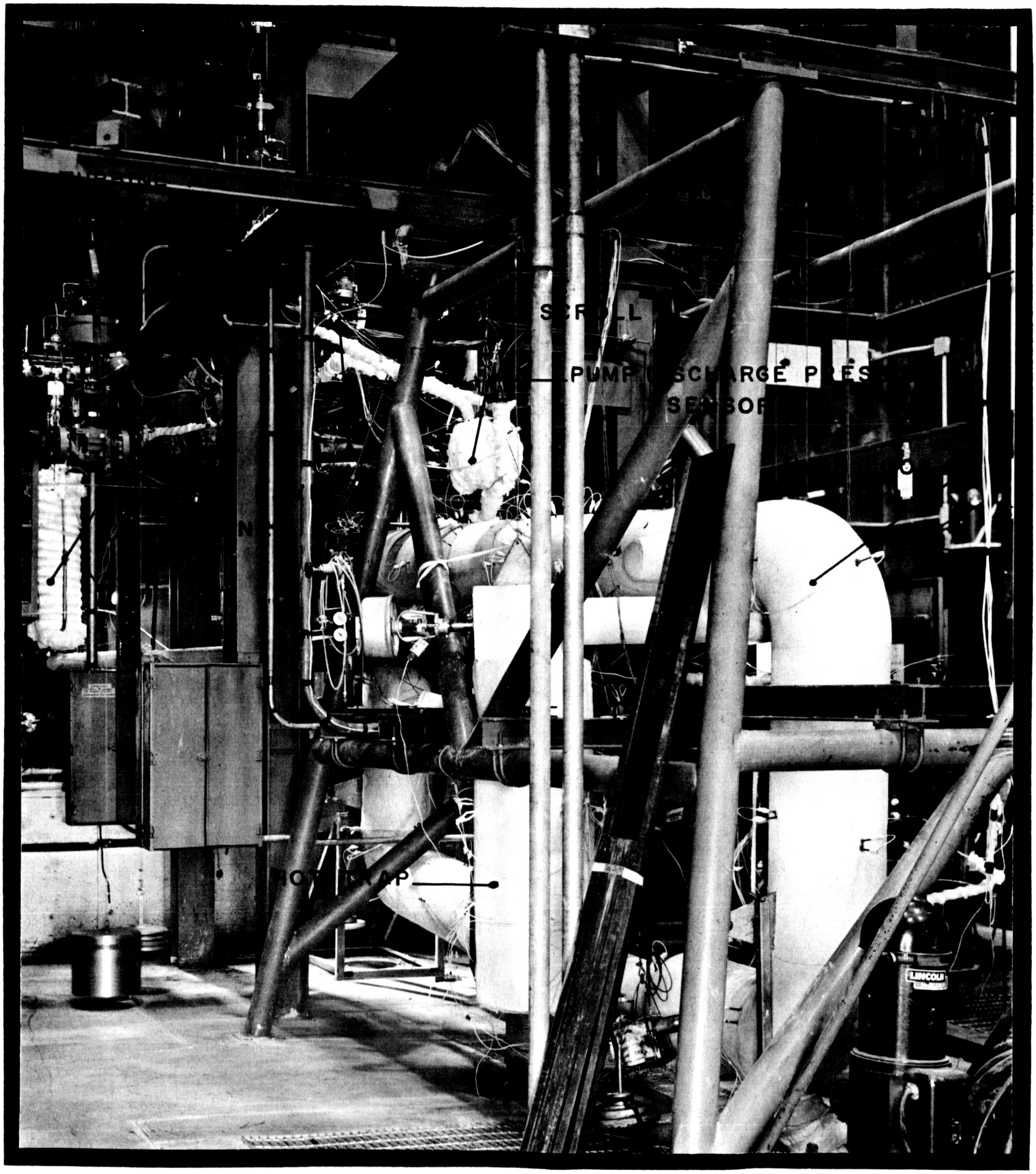


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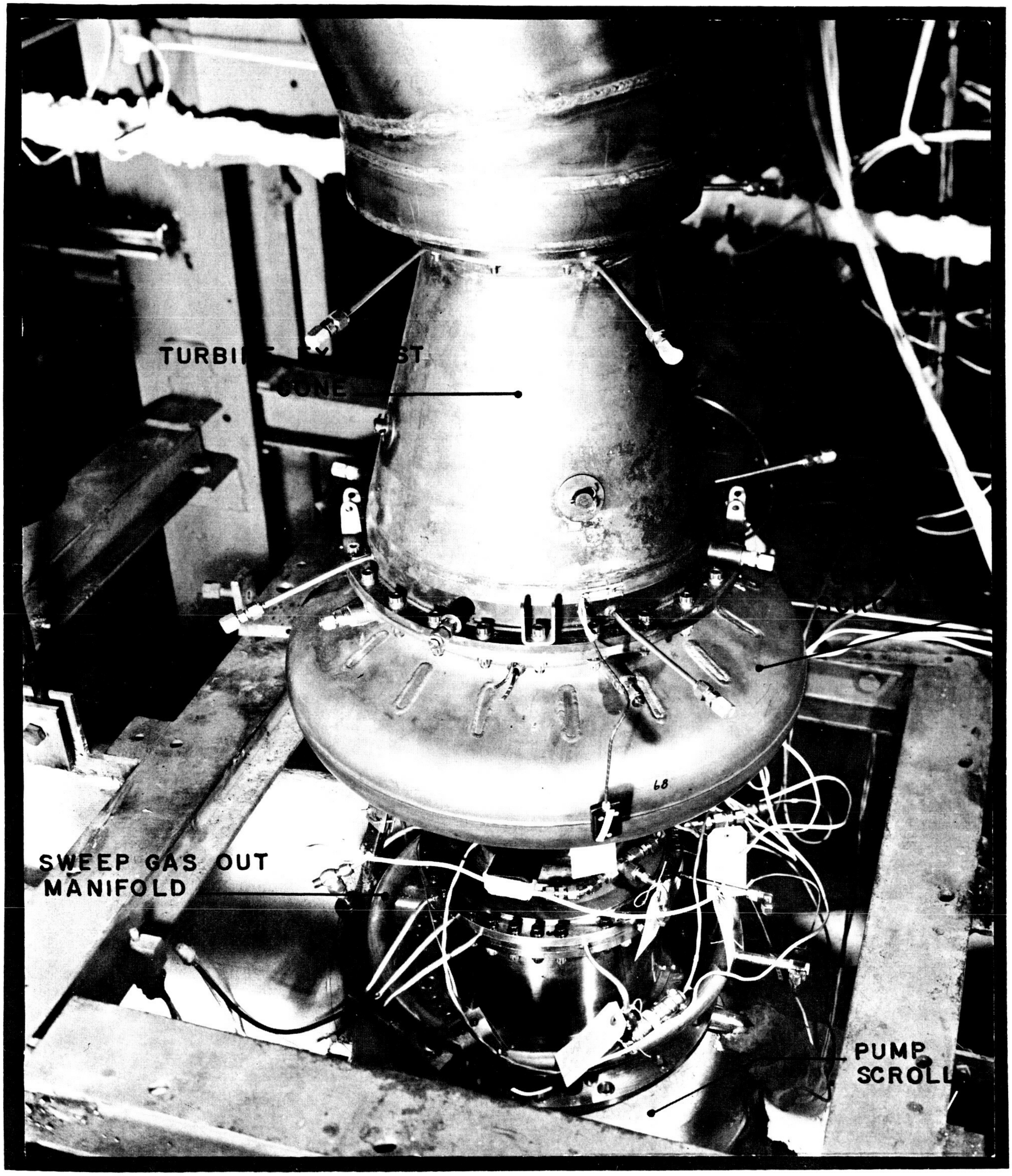
FIG 13

TP-1 TURBOPUMP PARTIALLY INSTALLED IN PT-6 TEST STAND



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