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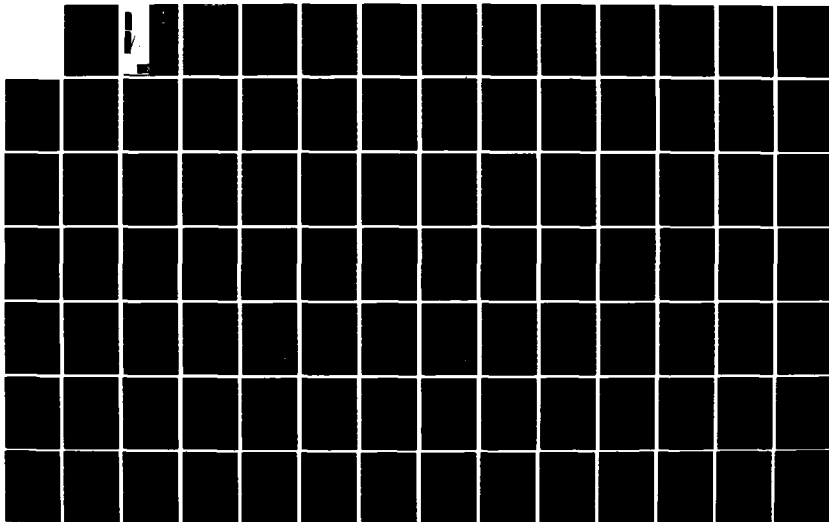
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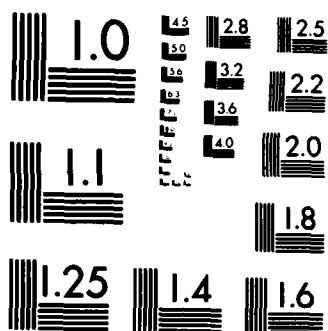
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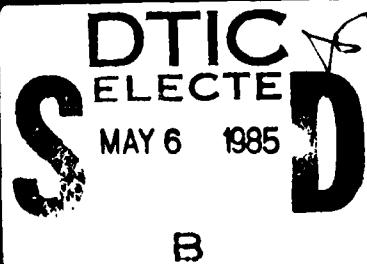
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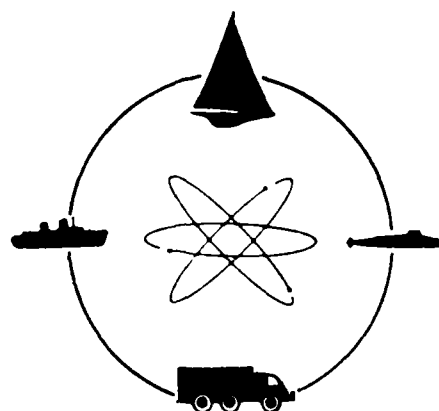
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## DAVIDSON LABORATORY

Report SIT-DL-85-9-2518

March 1985

DESIGN PROCEDURES FOR LOW SPEED  
WATERJETS SUITABLE FOR APPLICATION  
IN AMPHIBIOUS VEHICLES

by

John K. Roper  
Consultant

Prepared for

Code 1120

David W. Taylor Naval Ship Research  
and Development Center

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| Trials performance of an axial flow pump, used for waterjet propulsion in a<br>manned testcraft, was analyzed, compared to design predictions, and then used<br>to modify pump design procedures as appropriate. Performance estimates have<br>been made for a new waterjet unit for the testcraft, and also for a larger<br>unit which could be used in a prototype high-speed amphibious vehicle. |                       |                                                                |

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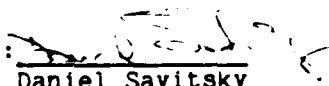
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APPROVED:   
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Director

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## INTRODUCTION

The U.S. Marine Corps is supporting an effort to increase the efficiency of waterjet propulsion units in existing amphibious vehicles. Reference 1 details the design of three axial-flow pumps, including one for an existing LVTP-7A1 which runs at speeds below 8 miles per hour. The other two pumps were designed to provide cavitation-free performance at propulsive coefficients in the region of 40 to 45 percent at a vehicle water speed of 20 mph. State-of-the art composite material technology was used wherever possible to reduce weight.

Next, a manned testcraft was constructed to evaluate a 14-inch diameter waterjet unit at vehicle speeds up to 25 mph in water. Reference 2 presents an analysis of initial trials conducted in August 1983.

A more comprehensive trial of the testcraft was run in July 1984 and test data have been reduced and analyzed. This report presents:

- A comparison of waterjet design predictions and July 1984 trial results.
- A waterjet design procedure, modified as appropriate to reflect trial experience.
- Performance estimates for a new 14-inch diameter axial-flow pump, designed for the existing testcraft.
- Performance estimates for a 16-inch diameter axial-flow pump unit, designed for possible use in a prototype high-speed amphibious vehicle.

This work was performed under Office of Naval Research Contract N00014-83-C-0780. Mr. Walter Zeitfuss of the U.S. Marine Corps Program Office, Code 112 DTNSRDC, was technical monitor of the project.

## PREDICTED PUMP PERFORMANCE CHARACTERISTICS

Design procedures detailed in Reference 1 were applied to predict head losses in the waterjet system as follows.

- a. For inlet entrance lengths of 33, 23 and 19.5 inches
  - Head losses: at entrance; in duct; and due to impeller shaft.

- b. Losses due to duct-to-casing transition, shaft bearing tube and struts.
- c. Losses due to friction in impeller casing.
- d. Losses in 10.5-inch and 12.25-inch exit diameter nozzles; losses due to drag of pitot tubes and pitot tube rack.

All of these head losses were expressed as functions of flow rate  $Q$ . Total head loss, less inlet head recovery as a function of vehicle speed, must equal the pump head required  $H_p$ . A prediction of power required to drive the pump is:

$$\text{SHP} = H_p Q \rho g / 550 \eta_p$$

where pump efficiency  $\eta_p$  was taken as 0.72 based on testcraft trial results.

Appendix A presents nomenclature for this and subsequent sections. Appendix B contains all the calculations of pump performance predictions.

#### ANALYSIS OF PUMP TEST RESULTS

Waterjet testcraft trials in July 1984 covered an extensive matrix of three inlet lengths, three (nozzle dia./casing dia.) ratios, and three impeller area ratios. A review of trial data showed that a detailed analysis of the 1.5 area ratio impeller coupled with the 12.25-inch exit diameter nozzle and the three inlet lengths, would furnish the most useful results for comparison with design predictions.

Accordingly, tabulations of performance data for the chosen impeller and nozzle at each of the three inlet lengths are presented on Pages C-1 through C-3 of Appendix C. Trends of waterjet thrust, SHP, and overall propulsive coefficient with testcraft speed are charted on pages C-4, 5 and 6 respectively. Bollard pull test results for pump efficiency  $\eta_p$  and impeller advance coefficient  $J$  are charted against SHP on Pages C-7 and C-8 respectively. The trends show that  $\eta_p$  and  $J$  are reasonably constant with SHP, and therefore,  $\eta_p = 0.72$  and  $J = 0.82$  were chosen for use in subsequent design predictions.

Next, a tabulation was prepared to show a comparison between measured bollard pull and predicted jet thrust as calculated from measured flow velocity, Page C-9. A chart of measured and predicted thrust versus

flow rate  $Q$  shows good agreement between the two sets of thrust values, Page C-10.

Inlet losses, in the bollard test condition were predicted by using the relationships developed in Appendix B and summarized on Page B-15. Predicted losses were then compared to static head measurements taken at the aft end of the inlet duct, for each of the three inlet lengths, Pages C-11 through C-16. Good agreement between predicted and measured head loss in the three inlets is demonstrated for the bollard test condition.

Actual head recovery in the inlet was assumed equal to the difference between inlet loss at forward speed and inlet loss at zero speed (bollard pull test) at a given flow rate  $Q$ . Tabulations on Pages C-17, 18 and 19 list measured static head at the aft end of the inlet duct during speed runs for each of the three inlet lengths; also listed are flow rate  $Q$  and craft speed. Bollard test inlet loss was then calculated by using the inlet loss prediction relations, Page B-15, and measured flow rate  $Q$ . Speed test inlet loss was determined from measured static head in the inlet.

A chart on Page C-20 presents head recovered,  $H_O$ , versus craft speed  $V_O$ . Actual test values of  $H_O$  are compared to a predicted curve of  $H_O$  based on an assumption of a 100 percent recovery of dynamic head  $V^2/2g$ . The chart shows that 100 percent dynamic head recovery is a reasonable assumption.

Total pump head  $H_p$  was determined from measurements of impeller shaft thrust  $T_s$  by:

$$H_p = T_s / \rho g A$$

where casing area  $A = 1.087$  square feet. Total pump head required was predicted using measured flow rate  $Q$  and vehicle speed  $V_O$  in the equations summarized on Page B-15. Tabulations of measured and predicted pump head are presented on Pages C-21, 22 and 23. A chart on Page C-24 shows good agreement between measured and predicted  $H_p$ .

Shaft horsepower SHP was determined from impeller shaft torque and revolution measurements. An SHP prediction was obtained for each test run by using measured flow rate  $Q$  and predicted pump head  $H_p$  in:

$$\text{Predicted SHP} = H_p Q \rho g / 550 \eta_p$$

where a pump efficiency  $\eta_p = 0.72$  was chosen on the basis of bollard pull test results. Tabulations of Actual and Predicted SHP are given on pages C-25 and C-26; a chart of Predicted versus Actual SHP, Page C-27, shows

generally good agreement between the two SHP values.

### Cavitation Inception

This waterjet propulsion system uses a marine-type propeller as the impeller of an axial flow pump. In evaluating cavitation inception limits, cavitation criteria for pumps and for marine propellers were used.

Reference 3, for example, defines the term "net positive suction head" or NPSH as the excess of absolute pressure over vapor pressure at a pump inlet, and also cites a dimensional characteristic "suction specific speed",  $S$ , as a useful index of pump rating:

$$S = N\sqrt{Q'} / (\text{NPSH})^{.75}$$

$N$  = shaft rpm

$Q'$  = flow rate, gpm

$(\text{NPSH})$  = net head, ft

For application to the waterjet system, the equation has been adapted as follows:

$$S = 21.19 N\sqrt{Q} / (H_{IS} - H_{VAP})^{.75}$$

where:

$Q$  = flow rate, cu.ft/sec

$H_{IS}$  = static head in inlet, ft abs

$H_{VAP}$  = head equivalent of vapor pressure, ft abs

Pages C-28 through C-30 show tabulations of  $S$  and impeller shaft thrust coefficient  $K_T$  for the 1.5 area ratio impeller/12.25 inch nozzle and three inlet lengths.  $K_T$  is charted versus  $S$  on Page C-31.

As shaft speed  $N$  increases,  $Q$  increases and net head at the inlet decreases, resulting in a large increase in  $S$ . The chart shows that:

- $K_T$  is essentially constant as  $S$  increases for all bollard pull test runs.
- $K_T$  gradually decreases as  $S$  increases for all speed runs.

Cavitation inception would be indicated by a sharp drop in thrust coefficient at high values of  $S$ ; no such drop is evident for the test conditions shown.

Next, calculations of criteria for cavitation inception on marine propellers were made for all trial data (3 impellers, 3 nozzle openings, 3 inlet lengths). Cavitation index  $\sigma$  is usually calculated as the ratio (net head at propeller blade tip) / (dynamic head due to resultant tip velocity). However, trial results have shown that advance coefficient  $J$  is essentially constant over the impeller operating range, i.e. the ratio of (axial fluid velocity) / (tangential tip velocity) is constant. This suggests that a cavitation index based on axial fluid velocity would be a useful simplification.

Pages C-32 through C-34 are tabulations of thrust coefficient  $K_T$  and conventional cavitation index  $\sigma_t$  based on resultant tip velocity. Page C-35 is a chart of  $K_T$  versus  $\sigma_t$  for all tests of the 1.50 area ratio impeller/12.25 inch nozzle with three inlet lengths. Since  $\sigma_t$  varies approximately as the inverse of pump specific speeds, trends of  $K_T$  as  $\sigma_t$  decreases are similar to trends of  $K_T$  as  $S$  increases, Page C-31.

Page C-36 shows tabulations of  $\sigma$ ,  $K_T$  and pump efficiency  $\eta_p$  for bollard pull tests of the three impellers with a common nozzle (12.25 inch) and inlet length (33 inches), where  $\sigma$  is based on axial flow velocity at the impeller.  $K_T$  is charted versus  $\sigma$  on Page C-37, and  $\eta_p$  is plotted against  $\sigma$  on Page C-38. In each chart, there is a sharp drop in thrust coefficient and pump efficiency for the 1.0 area ratio impeller at the highest flow rate (lowest  $\sigma$ ), implying a possible inception of cavitation.

Page C-39 lists inlet pressures from bollard pull tests of three impellers combined with a 33-inch inlet length and selected nozzle openings. These measured pressures are plotted versus flow rate  $Q$  on Page C-40. Also shown is a curve of predicted inlet pressures from the equation for inlet head loss, Page C-15, which is in good agreement with measured pressures.

On the basis of the cavitation criteria examined, it may be tentatively concluded that:

- A 1.0 area ratio impeller shows evidence of cavitation inception at a  $\sigma$  below 2, whereas the two larger area impellers show no such evidence to a  $\sigma$  of about 0.75 at the highest speed tested.
- For cavitation-free performance and highest pump efficiency, the 1.5 area ratio is the choice over the 2.25 area ratio impeller.

Thus, attention in subsequent comparisons will be focused on the 1.5 area ratio impeller.

Calculations of  $\sigma$ ,  $K_T$ ,  $\eta_p$  and  $J$  are listed on pages C-41 through C-43 for the 1.5 area ratio impeller/12.25 inch nozzle with three inlet lengths. Charts of the latter three quantities versus  $\sigma$  appear on pages C-44, C-45 and C-46.

While during the bollard tests all three quantities remained essentially constant, showing no sign of degradation with decreasing cavitation number, the tests at speed showed a reduction in  $K_T$  with decreasing  $\sigma$ .

Since it was felt that this might be due to aeration of the flow into the pump when planing at high speeds, a plot of thrust coefficient against volume Froude number was made showing that  $K_T$  decreases as  $F_v$  increases, a result which tends to confirm the presence of ventilation. The data for this plot, shown on page C-49, are tabulated on pages C-47 and C-48.

In any case, for volume Froude numbers corresponding to full scale speeds of 15-25 mph, (hump-cruise)  $K_T$  is diminished only slightly to approximately 85 percent of its maximum value. This degradation could be restored by an increase in impeller speed of only 7 or 8 percent.

#### ESTIMATED PUMP PERFORMANCE CHARACTERISTICS

This section presents a waterjet system design procedure which integrates practical design factors obtained during the July 1984 trials. The initial application is in a design of a modified 14-inch diameter axial flow pump which can be evaluated using the existing testcraft hull and engine. The following particulars and design factors were selected:

- Inlet entrance length of 19.5 inches to minimize overall length of system, since trial results showed no consistent penalty associated with this shortest of the inlet lengths tested.
- A nozzle with a profile as sketched on Page E-1, and an exit diameter of 12 inches.
- 100 percent recovery of dynamic head due to vehicle velocity.
- Limiting values of cavitation index  $\sigma$  ranging from 0.75 to 1.0.

- Propeller characteristic estimates based on a pump efficiency of 0.72 and an impeller advance coefficient of 0.82.

Nozzle configuration and experimental data on nozzle performance were taken from Reference 4. The nozzle profile, Page E-1, causes a contraction of the waterjet beyond the nozzle mouth. This effective waterjet diameter and a head loss coefficient were obtained from the referenced data.

Using the above design particulars, estimates of pump performance characteristics are detailed on Pages D-1 through D-14.

#### ESTIMATED PERFORMANCE FOR 14 INCH DIAMETER PUMP

Design procedures developed in the previous section have been applied to predict performance of the pump system shown on Page E-1.

The initial step was to develop curves of pump shaft horsepower for nominal values of flow rate and vehicle speed, Page E-4. These curves were then used to obtain flow rate corresponding to nominal values of shaft power and vehicle speed, leading to the construction of curves of jet thrust versus vehicle speed for each nominal shaft horsepower, Page E-9. Nominal values of SHP were chosen to cover the operating range of the existing testcraft engine.

To avoid cavitation, flow rate is limited by a relationship with vehicle speed and a minimum value of cavitation index  $\sigma$ . This equation, developed on Page D-13, was evaluated for  $\sigma = 0.75$  and 1.0 to yield cavitation-free flow rate and jet thrust. Curves of jet thrust versus vehicle speed for the two values of cavitation index are superposed on the chart on Page E-9. The two sets of curves show clearly that at top vehicle speed, full engine power should be absorbed by the pump without inception of cavitation.

A chart of predicted overall propulsive coefficient versus SHP, Page E-10 shows that a target of 40 to 45 percent propulsive efficiency can be achieved at a vehicle speed of 20 mph. A chart of pump rpm versus pump SHP predicts that full engine power can be absorbed at top vehicle speed within the engine shaft speed limit.

## ESTIMATED PERFORMANCE FOR 16 INCH DIAMETER PUMP

A proposed pump for a high-speed amphibious vehicle is sketched on Page F-1. This 16-inch diameter pump is geometrically similar in certain respects to the 14-inch pump described in the previous section. Inlet dimensions and nozzle exit diameter have been increased by a ratio (16/14), but the overall length of the unit has been changed only two percent. Given the above similarities, performance of the 16-inch pump has been predicted by making the following assumptions.

- Range of craft speed  $V_o$  will be identical with that used for 14-inch pump.
- Waterjet velocity  $V_j$  and pump head  $H_p$  will be independent of pump diameter
- Impeller advance coefficient  $J = 0.82$  and pump efficiency  $\eta_p = 0.72$  as for 14-inch pump.
- Flow rate of 16-inch pump  $Q_{16} = Q_{14} (16/14)^2$

It then follows that.

- Since  $SHP = H_p Q / \eta_p$ ,  $SHP_{16} = SHP_{14} (16/14)^2$
- Since  $T_j = Q (V_j - V_o)$ ,  $T_{j16} = T_{j14} (16/14)^b$
- Since  $J = V / ND = (Q/A) / ND$

$$\text{or } ND = Q/AJ$$

But  $Q/AJ$  has been assumed constant

$$\text{Thus } ND \text{ is constant and } N_{16} = 14N_{14}/16$$

These relations were applied to the 14-inch pump predictions to obtain performance estimates for a 16-inch pump. Calculations and charts of performance characteristics are detailed on Pages F-2 through F-9.

REFERENCES

1. Roper, John K. "Development of Waterjet Propulsion Unit", Davidson Laboratory Report 2328, March 1982.
2. Numata, E., "Performance Trial of a Manned Waterjet Testcraft", Davidson Laboratory Report 2390, March 1984.
3. Marks' Standard Handbook for Mechanical Engineers (8th. Ed.), McGraw-Hill Book Company.
4. Ellis, W.E. and Sobolewski, A.D. "Propulsion Experiment with a Planing Hull Having Two Flush Inlet Configurations" DTNSRDC/SPD-0786-01, March 1978.

APPENDIX A

# NOMENCLATURE

|            |                                                          |                      |
|------------|----------------------------------------------------------|----------------------|
| $A_I$      | = INLET AREA (JUST AHEAD OF PROP.)                       | FT <sup>2</sup>      |
| $A_J$      | = JET AREA (AT MINIMUM JET DIAM.)                        | FT <sup>2</sup>      |
| $A_P$      | = FLOW AREA AT PROP. (= $A_I$ )                          | FT <sup>2</sup>      |
| $P_{S1}$   | = MEASURED PRESSURE IN INLET (JUST AHEAD OF PROP.)       | PSIG                 |
| $D$        | = PROP. DIAM.                                            | FT                   |
| $H_{atm}$  | = HEAD DUE TO ATMOSPHERIC PRESSURE                       | FT                   |
| $H_{I_s}$  | = INLET STATIC HEAD                                      | FT                   |
| $H_0$      | = HEAD RECOVERED FROM FREE STREAM                        | FT                   |
| $H_P$      | = PUMP HEAD                                              | FT                   |
| $H_{PCAV}$ | = PUMP HEAD AT CAVITATION LIMIT                          | FT                   |
| $H_{VAP}$  | = HEAD CORRESPONDING TO VAPOR PRESSURE                   | FT                   |
| $H_{Lc}$   | = CASING HEAD LOSS                                       | FT                   |
| $H_{L_I}$  | = INLET HEAD LOSS                                        | FT                   |
| $H_{L_J}$  | = NOZZLE HEAD LOSS                                       | FT                   |
| $H_{L_M}$  | = HEAD LOSS DUE TO MEASURING EQUIP.                      | FT                   |
| $d$        | = PROP. ADVANCE COEF. = $\frac{V_a}{nD}$                 |                      |
| $K_c$      | = CAVITATION INDEX = $\frac{H_0/PAR}{H_{I_s} - H_{VAP}}$ |                      |
| $K_T$      | = PROP. THRUST COEF. = $\frac{T}{\rho n^2 D^4}$          |                      |
| $n$        | = PROP. SPEED                                            | RPS                  |
| $N$        | = PROP. SPEED                                            | RP/Min               |
| $OPC$      | = OVERALL PROPULSIVE COEF. = $\frac{T_a V_0}{550 SHP}$   |                      |
| $PAR$      | = PROJECTED AREA RATIO OF PROP.                          |                      |
| $Q$        | = FLOW RATE                                              | FT <sup>3</sup> /SEC |
| $R_M$      | = RESISTANCE OF MEASURING EQUIP.                         |                      |

# NOMENCLATURE (CONT.)

|           |   |                                     |   |                                                     |        |
|-----------|---|-------------------------------------|---|-----------------------------------------------------|--------|
| $RDR$     | = | RAM PRESSURE RECOVERY RATIO         | = | $\frac{H_0}{V_0^2/2g}$                              |        |
| $S$       | = | SUCTION SPECIFIC SPEED              | = | $21.19 \frac{(Q)^{1/2}}{(H_{E_2} - H_{vap})^{3/4}}$ |        |
| $SHP$     | = | POWER TO PUMP                       |   |                                                     | HP     |
| $T_B$     | = | BOLLARD PULL                        |   |                                                     | lb     |
| $T_J$     | = | JET THRUST                          |   |                                                     | lb     |
| $T_S$     | = | SHAFT (PROP.) THRUST                |   |                                                     | lb     |
| $V_E$     | = | INLET VELOCITY (JUST AHEAD OF PUMP) |   |                                                     | FT/SEC |
| $V_J$     | = | JET VELOCITY (AT MINIMUM JET DIAM)  |   |                                                     | FT/SEC |
| $V_{MPU}$ | = | CRAFT SPEED                         |   |                                                     | MPH    |
| $V_0$     | = | CRAFT SPEED                         |   |                                                     | FT/SEC |
| $V_P$     | = | VELOCITY AT PROP. (= $V_T$ )        |   |                                                     | FT/SEC |
| $\eta_p$  | = | PUMP EFFICIENCY                     | = | $\frac{PQ H_0 Q}{550 SHP}$                          |        |

APPENDIX B

# PREDICTED INLET LOSSES

## SUMMARY

|                               | <u>33" INLET</u> | <u>23" INLET</u> | <u>19.5" INLET</u> |
|-------------------------------|------------------|------------------|--------------------|
| ENTRANCE                      | .8669            | 1.7856           | 2.4820             |
| DUCT FRICTION + BEND          | 1.8365           | 2.6055           | 3.3875             |
| SHAFT                         | .3232            | .2699            | 1.1749             |
| TRANSITION                    | 1.4691           | 1.4691           | 1.4691             |
| BENDING TUBE (FRICTION)       | .0752            | .0752            | .0752              |
| BENDING TUBE (FRONTAL)        | .3247            | .3247            | .3247              |
| STUTTS (PROFILE)              | .1866            | .1866            | .1866              |
| STUTTS (INTERFERENCE)         | <u>.0093</u>     | <u>.0093</u>     | <u>.0093</u>       |
| HLI                           | 5.0915           | 7.2259           | 9.1093             |
| $K = \frac{HLI}{Q_{NON}^2} =$ | .002037          | .002890          | .003755            |

## PREDICTED INLET LOSSES

### ENTRANCE (33" INLET)

$$Q = \text{NOV. FLOW RATE} = 50 \text{ FT}^3/\text{SEC}$$

$$A = \text{ENTRANCE AREA} = \frac{(14)(33)}{144} = 3.208 \text{ FT}^2$$

$$V = \text{ENTRANCE VELOCITY} = \frac{Q}{A} = \frac{50}{3.208} = 15.58 \text{ FT/SEC}$$

$$K = \text{LOSS COEFF.} = .23$$

(CRANE, "SLIDING PLATE" ENTRANCE)

$$HL = K \frac{V^2}{2g} = \frac{(.23)(15.58)^2}{2(32.2)} = .8669'$$

### ENTRANCE (23" INLET)

$$Q = 50 \text{ FT}^3/\text{SEC}$$

$$A = \frac{(14)(23)}{144} = 2.2361 \text{ FT}^2$$

$$V = \frac{Q}{A} = \frac{50}{2.2361} = 22.36 \text{ FT/SEC}$$

$$K = .23$$

$$HL = K \frac{V^2}{2g} = \frac{(.23)(22.36)^2}{2(32.2)} = 1.7856'$$

### ENTRANCE (19.5" INLET)

$$Q = 50 \text{ FT}^3/\text{SEC}$$

$$A = \frac{(14)(19.5)}{144} = 1.8958 \text{ FT}^2$$

$$V = \frac{Q}{A} = \frac{50}{1.8958} = 26.39 \text{ FT/SEC}$$

$$K = .23$$

$$HL = K \frac{V^2}{2g} = \frac{(.23)(26.39)^2}{2(32.2)} = 2.962'$$

## PREDICTED INLET LOSSES

### DUCT FRICTION & BEND (33' INLET)

$$Q = \text{VOL. FLOW RATE} = 50 \text{ ft}^3/\text{SEC}$$

$$A = \text{DUCT AREA} = \frac{(14)(\pi)}{4} = 1.6528 \text{ ft}^2$$

$$V = \text{DUCT VELOCITY} = Q/A = \frac{50}{1.6528} = 30.25 \text{ ft/sec.}$$

$$d_e = \text{EQUIV. DUCT DIAM.} = \frac{4A}{\pi} = \frac{4(1.6528)(12)}{\pi} = 1.2796'$$

$$Re = \frac{V d_e}{\nu} = \frac{(30.25)(1.2796)}{1.24 \times 10^{-5}} = 3.12 \times 10^6$$

$$e = \text{ROUGHNESS} = .000005'$$

(CRANE - SIM. TO DRAWN TUBES)

$$e/d_e = .000005/1.2796 = .0000039$$

$$f = \text{FRICTION FACTOR} = .0097$$

(CRANE)

$$L_D = \text{DUCT LENGTH} = \sqrt{16.5^2 + 6.5^2} = 17.8' \approx 1.18'$$

$$L_B = \text{EQUIV. LENGTH OF BEND} = \frac{L}{R} d_e^2 \left( \frac{V}{90} \right) = (36)(1.2796) \left( \frac{30.25}{90} \right) = 15.87'$$

$$L = \text{TOT EQUIV. LENGTH} = L_D + L_B = 1.18 + 15.87 = 17.05'$$

$$HL = f \left( \frac{L}{d_e} \right) \frac{V^2}{2g} = (.0097) \left( \frac{17.05}{1.2796} \right) \left( \frac{30.25^2}{2(32.2)} \right) = 1.8365'$$

## PREDICTED INLET LOSSES

### DUCT FRICTION + BEND (23" INLET)

$$Q = 50 \text{ ft}^3/\text{sec}$$

$$A = \frac{(14)(12)}{144} = 1.16528 \text{ ft}^2$$

$$V = Q/A = 50/1.16528 = 30.25 \text{ ft/sec}$$

$$d_e = \frac{4A}{2\left(\frac{14+12}{12}\right)} = \frac{4(1.16528)(12)}{2(14+12)} = 1.2796'$$

$$Re = \frac{V d_e}{1.24 \times 10^{-5}} = \frac{(30.25)(1.2796)}{1.24 \times 10^{-5}} = 3.12 \times 10^6$$

$$e = .000005'$$

$$e/d_e = .000005/1.2796 = .0000039$$

$$f = .0097$$

$$L_D = \sqrt{(11.5)^2 - (8.5)^2} = 7.75 = 5.5'$$

$$L_B = \left(\frac{L}{D}\right) d_e \left(\frac{V}{90}\right) = (36)(1.2796) \left(\frac{46}{90}\right) = 23.54'$$

$$L = L_D + L_B = .65 + 23.54 = 24.19'$$

$$HL = f \left(\frac{L}{d_e}\right) \frac{V^2}{2g} = (.0097) \left(\frac{24.19}{1.2796}\right) \frac{(30.25)^2}{2(32.2)} = 2.6055'$$

## PREDICTED INLET LOSSES

### DUCT FRICTION + BEND (19.5" INLET)

$$Q = 50 \text{ ft}^3/\text{sec}$$

$$A = \frac{(14)(12)}{144} = 1.1667 \text{ ft}^2$$

$$V = Q/A = \frac{50}{1.1667} = 42.86 \text{ ft/sec}$$

$$d_e = \frac{4A}{\pi(N+1)} = \frac{4(1.1667)(12)}{\pi(14+1)} = 1.2796'$$

$$Re = \frac{V d_e}{\nu} = \frac{(42.86)(1.2796)}{1.24 \times 10^{-5}} = 3.12 \times 10^6$$

$$\epsilon = .000005$$

$$\epsilon/d_e = .000005/1.2796 = .0000039$$

$$f = .0097$$

$$L_D = \frac{1}{f} \left( \frac{V}{c} \right)^2 = \frac{1}{.0097} \left( \frac{42.86}{1115} \right)^2 = 4.78'' = .40'$$

$$L_B = \left( \frac{L}{D} \right)_B d_e \left( \frac{V}{c} \right) = (36)(1.2796) \left( \frac{42.86}{1115} \right) = 3.105'$$

$$L = L_D + L_B = .40 + 3.105 = 3.505'$$

$$HL = f \left( \frac{L}{d_e} \right) \frac{V^2}{2g} = (.0097) \left( \frac{3.505}{1.2796} \right) \frac{(42.86)^2}{2(32.2)} = 3.3875'$$

## PREDICTED INLET LOSSES

### SHAFT (33" INLET)

$$Q = \text{NOV. FLOW RATE} = 50 \text{ ft}^3/\text{SEC.}$$

$$A = \text{DUCT AREA} = 1.6528 \text{ ft}^2$$

$$V = \text{DUCT VELOCITY} = Q/A = 50/1.6528 = 30.25 \text{ ft/SEC}$$

$$C_D = \text{DRAG COEF.} = 1.1 \sin^2 \alpha = 1.1 \sin^2 31.01 = .1504$$

$$L = \text{SHAFT LENGTH} = 2'$$

$$d = \text{SHAFT DIAM.} = 1.50" = .125'$$

$$D = \text{SHAFT DRAG} = C_D \left( \frac{\rho}{2} \right) V^2 L d = (.1504) \left( \frac{1.94}{2} \right) (30.25)^2 (.125) = 33.37'$$

$$HL = \frac{D}{\rho g A} = \frac{33.37}{(1.94)(32.2)(1.6528)} = .3232'$$

### SHAFT (23" INLET)

$$Q = 50 \text{ ft}^3/\text{SEC.}$$

$$A = 1.6528 \text{ ft}^2$$

$$V = Q/A = 50/1.6528 = 30.25 \text{ ft/SEC}$$

$$C_D = 1.1 \sin^2 \alpha = 1.1 \sin^2 46 = .4094$$

$$L = 1.75'$$

$$d = .125'$$

$$D = C_D \left( \frac{\rho}{2} \right) V^2 L d = (.4094) \left( \frac{1.94}{2} \right) (30.25)^2 (1.75)(.125) = 29.49'$$

$$HL = \frac{D}{\rho g A} = \frac{29.49}{(1.94)(32.2)(1.6528)} = .7609'$$

## PREDICTED INLET LOSSES

SHAFT (19.5" INLET)

$$Q = 50 \text{ cfs/sec}$$

$$A = 1.6528 \text{ ft}^2$$

$$V = Q/A = 50/1.6528 = 30.25 \text{ cfs/sec}$$

$$C_D = 1.1 \sin^2 \alpha = 1.1 \sin^2 60.67 = .7269$$

$$L = 1.5'$$

$$d = .125'$$

$$D = C_D \rho \frac{1}{2} L V^2 = (.7269) \left( \frac{1.94}{2} \right) (30.25)^2 (1.50)(.125) = 121.31'$$

$$HL = \frac{D}{\rho g A} = \frac{121.31}{(1.94)(32.2)(1.6528)} = 1.1749'$$

## PREDICTED INLET LOSSES

### TRANSITION

$$Q = \text{NOV. FLOW RATE} = 50 \text{ FT}^3/\text{SEC}$$

$$A = \text{AREA AT PROP. (SMALL END OF TRANSITION)} = \frac{(.96)(.35)(.1412)}{1.41} = 1.0434 \text{ FT}^2$$

$$V = \text{VELOCITY AT PROP} = Q/A = 50/1.0434 = 47.92 \text{ FT/SEC}$$

$$C_D = \text{DISCHARGE COEF.} = .98$$

$$K = \text{LOSS COEF.} = \frac{1}{C_D^4} - 1 = \frac{1}{(.98)^4} - 1 = .0412$$

$$HL = K \frac{V^2}{2g} = \frac{(.0412)(47.92)^2}{2(32.2)} = 1.4691'$$

### BEARING TUBE (FRUSTUM)

$$V = \text{VELOCITY AT PROP} = 47.92 \text{ FT/SEC}$$

$$L = \text{TUBE LENGTH} = .57'$$

$$Re = \frac{\rho V}{\mu} = \frac{(47.92)(.0005)}{1.24 \times 10^{-5}} = 2.59 \times 10^4$$

$$C_f = .00368$$

$$S = \text{TUBE HEAT LOSS} = .57 \left( \frac{2.80}{12} \right) = .4912'$$

$$D = \text{TUBE DRAG} = (C_f + 2000) S \rho \frac{V^2}{2} = (.00368 + 2000)(.004912)(.0005) \frac{(47.92)^2}{2} = 4.90'$$

$$HL = \frac{D}{\rho g A} = \frac{4.90}{(1.94)(32.2)(1.0434)} = .0752'$$

### BEARING TUBE (FRONTAL)

$$A_o = \text{FRONTAL AREA} = (.285)(.2112) = .0602 \text{ FT}^2$$

$$V = 47.92 \text{ FT/SEC}$$

$$C_D = \text{DRAG COEF.} = 1$$

$$D = \text{FRONTAL DRAG} = C_D A_o \frac{\rho}{2} V^2 = (1)(.0602) \left( \frac{.0005}{2} \right) (47.92)^2 = 2.116'$$

$$HL = \frac{D}{\rho g A} = \frac{2.116}{(1.94)(32.2)(1.0434)} = .3241'$$

## PREDICTED INLET LOSSES

### STRUTS (PROFILE)

$$Q = \text{NOM. FLOW RATE} = 50 \text{ FT}^3/\text{SEC.}$$

$$A = \text{AREA AT PROP.} = 1.0434 \text{ FT}^2$$

$$V = \text{VELOCITY AT PROP.} = Q/A = 50/1.0434 = 47.92 \text{ FT/SEC.}$$

$$C = \text{STRUT CHORD} = 3'' = .25'$$

$$Re = \frac{V_c}{\mu} = \frac{(47.92)(.25)}{1.24 \times 10^{-5}} = 9.66 \times 10^5$$

$$C_f = .00439$$

$$t/c = .3125/3 = .1042$$

$$C_D = 2(C_f \times .0005)(1 + 1.2 t/c) = 2(.00439 \times .0005)(1 + 1.2 \times .1042) = .0117$$

$$S = \text{STRUT PLANFORM AREA} = 2 \frac{(14 - 2.50)(3)}{144} = .4667 \text{ FT}^2$$

$$D = \text{STRUT DRAG} = C_D S \rho \frac{V^2}{2} = (.0117)(.4667) \left( \frac{1.94}{2} \right) (47.92)^2 = 12.16 \text{ LB}$$

$$HL = \frac{D}{\rho g A} = \frac{12.16}{(1.94)(32.2)(1.0434)} = .1866'$$

### STRUTS (INTERFERENCE)

$$A = 1.0434 \text{ FT}^2$$

$$V = 47.92 \text{ FT/SEC}$$

$$t = .3125/12 = .0260'$$

$$t/c = .1042$$

$$C_D = .75 t/c - \frac{.0003}{(t/c)^2} = (.75 \times .1042) - \frac{.0003}{(.1042)^2} = .0505$$

$$D = \text{INTERFERENCE DRAG} = 8 C_D t^2 \rho \frac{V^2}{2} = 8(.0505)(.026)^2 \left( \frac{1.94}{2} \right) (47.92)^2 = .6083 \text{ LB}$$

$$HL = \frac{D}{\rho g A} = \frac{.6083}{(1.94)(32.2)(1.0434)} = .0093'$$

## PREDICTED CASING LOSS

### CASING

$$Q = \text{NOMINAL FLOW RATE} = 50 \text{ ft}^3/\text{sec}$$

$$A = \text{CASING AREA} = (.785) \left( \frac{14.12}{12} \right)^2 = 1.017 \text{ ft}^2$$

$$V = \text{CASING VELOCITY} = Q/A = 50/1.017 = 49.16 \text{ ft/sec}$$

$$d = \text{CASING DIA} = 14.12" = 1.1767'$$

$$Re = \frac{Vd}{\nu} = \frac{(49.16)(1.1767)}{1.24 \times 10^{-5}} = 4.67 \times 10^6$$

$$e = \text{ROUGHNESS} = .000005'$$

$$e/d = .000005/1.1767 = .0000042$$

$$f = \text{FRICTION FACTOR} = .0095$$

$$L = \text{CASING LENGTH} = 1.33'$$

$$HL = f \left( \frac{L}{d} \right) \frac{V^2}{2g} = (.0095) \left( \frac{1.33}{1.1767} \right) \frac{(49.16)^2}{2(32.2)} = .3537'$$

$$K = \frac{HL}{Q^2} = \frac{.3537}{(50)^2} = .000141$$

$$HL_c = .000141 Q^2$$

## PREDICTED NOZZLE LOSSES

### 10.5" DIAM. NOZZLE

$$HL = \frac{V^2}{2g} (1+K)$$

$$\frac{V^2}{2g} = \left(\frac{Q}{A}\right)^2 \frac{1}{2g}$$

$$A = (.785)(10.5)^2 / 144 = .6010 \text{ ft}^2$$

$$\frac{V^2}{2g} = \frac{Q^2}{(.6010)^2 (1)(32.2)} = .0430 Q^2$$

$$1+K = \frac{1}{C_D^2}$$

$$C_D = .97$$

(ENR ENS. 154.38)

$$1+K = \frac{1}{(.97)^2} = 1.0628$$

$$HL = .0430 Q^2 (1.0628) = .045690 Q^2$$

### 12.25" DIAM. NOZZLE

$$HL = \frac{V^2}{2g} (1+K)$$

$$\frac{V^2}{2g} = \left(\frac{Q}{A}\right)^2 \frac{1}{2g}$$

$$A = (.785)(12.25)^2 / 144 = .8180 \text{ ft}^2$$

$$\frac{V^2}{2g} = \frac{Q^2}{(.8180)^2 (1)(32.2)} = .0232 Q^2$$

$$1+K = \frac{1}{C_D^2}$$

$$C_D = .97$$

$$1+K = \frac{1}{(.97)^2} = 1.0628$$

$$HL = .0232 Q^2 (1.0628) = .024664 Q^2$$

## PREDICTED NOZZLE LOSSES

14.00" NOZZLE (NO NOZZLE)

$$HL = \frac{V^2}{2g} (1+K)$$

$$\frac{V^2}{2g} = \left(\frac{Q}{A}\right)^2 \frac{1}{2g}$$

$$A = (78.5)(14.12)^2 / 144 = 1.087 \text{ ft}^2$$

$$\frac{V^2}{2g} = \frac{Q^2}{(1.087)^2 (2)(32.2)} = .013142 Q^2$$

$$K = 0$$

$$HL = .0131 Q^2 (1+0) = .013142 Q^2$$

## ESTIMATED MEASUREMENT LOSSES (12.25" NOZZLE)

### RACK

$$Q = \text{NOV. FLOW RATE} = 50 \text{ FT}^3/\text{SEC}$$

$$A = \text{NOZZLE EXIT AREA} = \frac{(.75")^2 (12.25')^2}{144} = .8130 \text{ FT}^2$$

$$V = Q/A = 50/.813 = 61.12 \text{ FT/SEC}$$

$$L = \text{RACK LENGTH} = 12.25' = 1.021$$

$$d = \text{RACK LEADING EDGE DIAM.} = .75" = .0625'$$

$$C_D = \text{DRAG COEF} = 1.1$$

$$R = C_D L d \frac{\rho}{2} V^2 = (1.1)(1.021)(.0625) \left(\frac{1.94}{2}\right) (61.12)^2 = 254.35^{\text{ft}}$$

### PILOT TUBES

$$L = \text{TUBE LENGTH} = 2(1.75 + 1.75 + 4.2 + 5.1 + 5.7 + 6.0) + 1(6.1 + 3.75) = 59.85' = 4.99'$$

$$d = \text{TUBE DIAM} = 3/32 = .009375'$$

$$C_D = 1.1$$

$$R = C_D L d \frac{\rho}{2} V^2 = (1.1)(4.99)(.009375) \left(\frac{1.94}{2}\right) (61.12)^2 = 155.40^{\text{ft}}$$

### TOTAL

$$R_t = 254.35 + 155.40 = 409.75^{\text{ft}}$$

$$H_{L_m} = \frac{R_t}{\rho g A} = \frac{409.75}{(1.94)(32.2)(.813)} = 8.02'$$

$$k = \frac{H_L}{Q^2} = \frac{8.02}{(50)^2} = .003207$$

$$K = \frac{D}{Q^2} = \frac{409.75}{(50)^2} = .1639$$

$$H_{L_m} = .003207 Q^2$$

# PREDICTED INLET PRESSURE RECOVERY

$$H_0 = RPR \frac{V_0^2}{2g}$$

$$RPR = 1.00$$

$$H_0 = (1.00) \frac{V_0^2}{2(32.2)} = .0155 V_0^2$$

# PREDICTED PUMP LEAD REQUIRED

$$H_p = H_{L1} + H_{Lc} + H_{L2} + H_{L4} - H_o$$

| <u>Nbr.</u> | <u>Incr</u> | <u>H<sub>L1</sub></u>  | <u>H<sub>Lc</sub></u>  | <u>H<sub>L2</sub></u> | <u>H<sub>L4</sub></u>  | <u>H<sub>o</sub></u> | <u>H<sub>p</sub></u>                          |
|-------------|-------------|------------------------|------------------------|-----------------------|------------------------|----------------------|-----------------------------------------------|
| 14.00       | 19.5        | .003755 Q <sup>2</sup> | .000141 Q <sup>2</sup> |                       | .013142 Q <sup>2</sup> | .0155 V <sup>2</sup> | .020245 Q <sup>2</sup> - .0155 V <sup>2</sup> |
|             | 23          | .002890 Q <sup>2</sup> |                        |                       |                        |                      | .019380 Q <sup>2</sup> - .0155 V <sup>2</sup> |
|             | 33          | .002037 Q <sup>2</sup> |                        |                       |                        |                      | .018527 Q <sup>2</sup> - .0155 V <sup>2</sup> |
| 12.25       | 19.5        | .003755 Q <sup>2</sup> |                        |                       | .024664 Q <sup>2</sup> |                      | .031767 Q <sup>2</sup> - .0155 V <sup>2</sup> |
|             | 23          | .002890 Q <sup>2</sup> |                        |                       |                        |                      | .030761 Q <sup>2</sup> - .0155 V <sup>2</sup> |
|             | 33          | .002037 Q <sup>2</sup> |                        |                       |                        |                      | .030049 Q <sup>2</sup> - .0155 V <sup>2</sup> |
| 10.50       | 19.5        | .003755 Q <sup>2</sup> |                        |                       | .045690 Q <sup>2</sup> |                      | .052793 Q <sup>2</sup> - .0155 V <sup>2</sup> |
|             | 23          | .002890 Q <sup>2</sup> |                        |                       |                        |                      | .051928 Q <sup>2</sup> - .0155 V <sup>2</sup> |
|             | 33          | .002037 Q <sup>2</sup> |                        |                       |                        |                      | .051075 Q <sup>2</sup> - .0155 V <sup>2</sup> |

PREDICTED SHP REQUIRED

$$SHP = \frac{H_p Q P q}{550 \eta_p}$$

$$\eta_p = .72$$

$$SHP = H_p Q \frac{(1.2)(32.5)}{(550)(.72)} = .1577 H_p Q$$

APPENDIX C

# PERFORMANCE DATA SUMMARY

1.5C Prop / 10.25" Nozzle / 23 in. H<sub>2</sub>O

0

| <u>RIN°</u> | <u>V<sub>WAT</sub></u> | <u>T<sub>g</sub></u> | <u>SHD</u> | <u>QAC</u> | <u>V</u> | <u>T<sub>p</sub></u> | <u>Q</u> |
|-------------|------------------------|----------------------|------------|------------|----------|----------------------|----------|
| 201         | 4.95                   | 33.1                 | 13         | 10.2       | .89      | .23                  | 16.06    |
| 202         | 5.00                   | 32.3                 | 103        | 12.0       | .90      | .25                  | 32.9     |
| 203         | 25.3                   | 90.5                 | 125        | 13.0       | .90      | .27                  | 40.35    |
| 204         | 25.3                   | 93.9                 | 134        | 13.1       | .90      | .27                  | 40.27    |
| 205         | 25.23                  | 105.4                | 98         | 13.1       | .93      | .27                  | 42.05    |
| 206         | 10.26                  | 96.5                 | 24         | 4.1        | .87      | .27                  | 27.48    |
| 207         | 10.93                  | 112.5                | 83         | 10.1       | .89      | .27                  | 29.32    |
| 208         | 8.19                   | 99.2                 | 51         | 4.5        | .88      | .26                  | 26.10    |
| 209         | 8.40                   | 103.5                | 51         | 4.54       | .89      | .26                  | 26.56    |
| 210         | 9.00                   | 92.1                 | 26         | 4.54       | .89      | .27                  | 27.02    |
| 211         | 9.03                   | 92.2                 | 26         | 4.53       | .89      | .23                  | 27.77    |
| 212         | "                      | 15.4                 | 3          | "          | .80      | .23                  | 8.00     |
| 213         | "                      | 4.1                  | 10         | 0          | .85      | .22                  | 14.76    |
| 214         | "                      | 9.43                 | 40         | 0          | .87      | .23                  | 27.04    |
| 215         | "                      | 15.1                 | 2          | 0          | .86      | .21                  | 25.30    |
| 216         | "                      | 22.6                 | 157        | 0          | .89      | .21                  | 31.10    |
| 217         | "                      | 29.53                | 215        | 0          | .91      | .23                  | 35.28    |
| 218         | 6.32                   | 13.2                 | 1          | 4.03       | .88      | .23                  | 9.25     |
| 219         | 11.1                   | 39.0                 | 141        | 13.2       | .88      | .24                  | 24.34    |
| 220         | 25.10                  | 100.1                | 201        | 13.40      | .90      | .25                  | 41.21    |

# PERFORMANCE DATA SUMMARY

1.50 Prop / 12.25 / 102, 19.5" INLET  $\Delta$

| <u>RUN</u> | <u>WPM</u> | <u>T<sub>0</sub></u> | <u>SHF</u> | <u>PA2</u> | <u>S</u> | <u>PA</u> | <u>Q</u> |
|------------|------------|----------------------|------------|------------|----------|-----------|----------|
| 221        | 4.16       | 1.27                 | 5          | .322       | .80      | .76       | 12.35    |
| 222        | 5.42       | 2.23                 | 16         | .327       | .84      | .83       | 12.76    |
| 223        | 5.23       | 3.36                 | 16         | .192       | .83      | .79       | 15.54    |
| 224        | 18.96      | 8.84                 | 13         | .210       | .86      | .84       | 33.81    |
| 225        | 20.93      | 8.43                 | 131        | .345       | .86      | .85       | 34.36    |
| 226        | 19.1       | 8.77                 | 70         | .332       | .84      | .83       | 26.16    |
| 227        | 6.32       | 5.11                 | 38         | .172       | .87      | .81       | 23.39    |
| 228        | 0          | 308                  | 6          | 0          | .85      | .62       | 11.41    |
| 229        | 0          | 624                  | 7          | 0          | .84      | .80       | 16.25    |
| 230        | 0          | 1523                 | 47         | 0          | .88      | .85       | 22.26    |
| 231        | 0          | 1602                 | 20         | 0          | .81      | .7        | 26.24    |
| 232        | 0          | 2354                 | 161        | 0          | .82      | .69       | 31.20    |
| 232        | 0          | 2365                 | 151        | 0          | .82      | .80       | 31.65    |
| 233        | 0          | 3.20                 | 221        | 0          | .83      | .83       | 36.35    |
| 234        | 4.22       | 3.1                  | 5          | .397       | .85      | .77       | 11.71    |
| 235        | 4.55       | 4.37                 | 10         | .361       | .92      | .84       | 16.82    |
| 236        | 15.42      | 7.57                 | .38        | .350       | .86      | .84       | 34.10    |
| 237        | 7.26       | 13.98                | 2          | 0          | 0        | 0         | 30.36    |
| 238        | 6.72       | 7.58                 | .92        | .289       | .82      | .83       | 26.7     |
| 239        | 15.5       | 12.07                | .25        | .476       | .74      | .80       | 33.11    |
| 240        | 67.05      | 9.66                 | .23        | .348       | .87      | .84       | 34.62    |
| 241        | 2.1        | 3.1                  | 4          | .38        | .88      | .83       | 26.27    |
| 242        | 7.81       | 3.4                  | 30         | .463       | .80      | .8        | 23.7     |
| 243        | 1.1        | 3.6                  | 17         | .401       | .81      | .82       | 14.99    |

# PERFORMANCE DATA SUMMARY

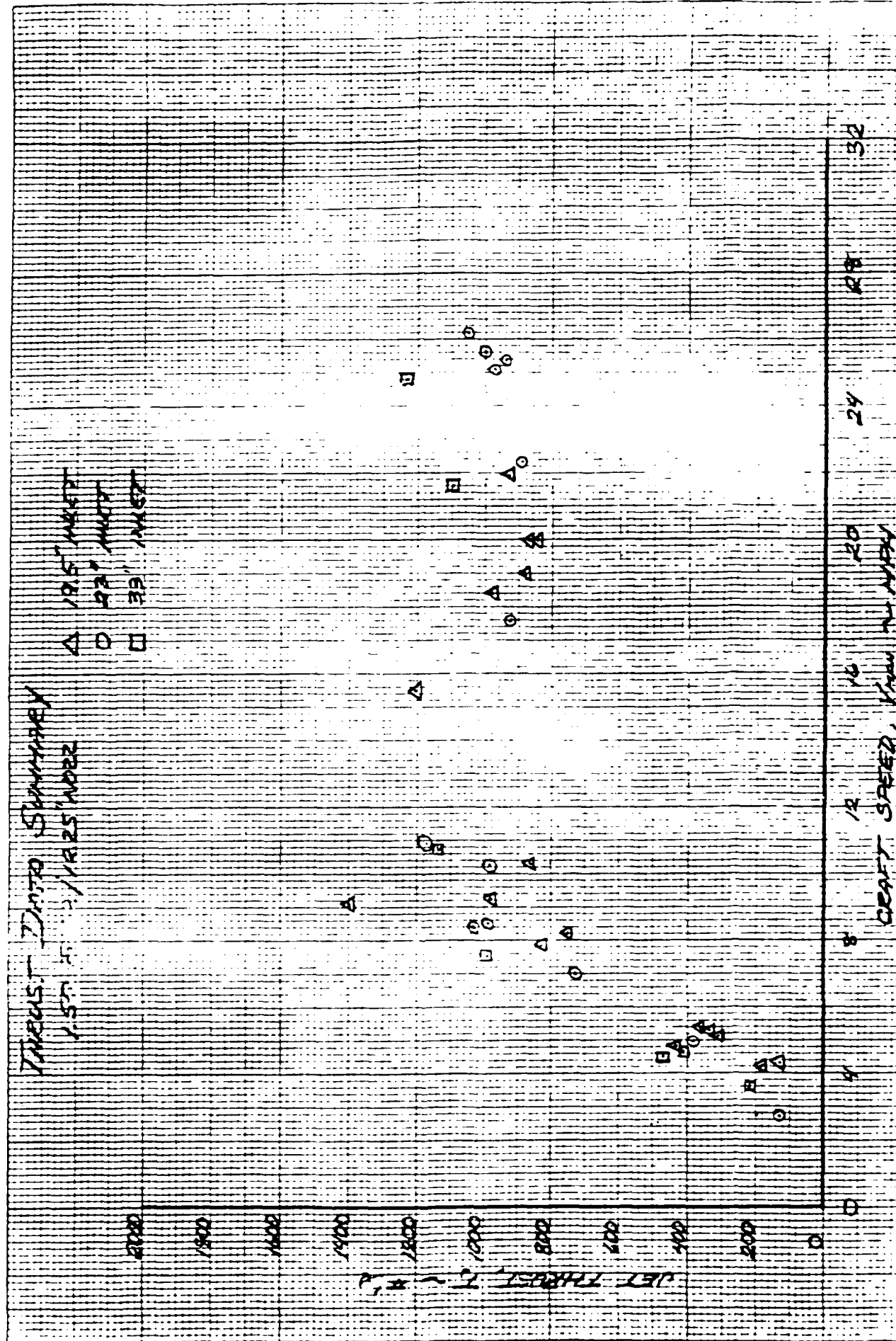
1.50 Prop / 12.25 1022 / 33 INLET ☐

| <u>Run #</u> | <u>V<sub>max</sub></u> | <u>T<sub>s</sub></u> | <u>SHP</u> | <u>Q<sub>max</sub></u> | <u>U</u> | <u>Z<sub>0</sub></u> | <u>Q</u> |
|--------------|------------------------|----------------------|------------|------------------------|----------|----------------------|----------|
| 241          | 3.2                    | 2.9                  | 5          | .303                   | .89      | .28                  | 12.02    |
| 245          | 4.55                   | 3.0                  | 15         | .372                   | .93      | .34                  | 12.25    |
| 246          | 4.55                   | 4.0                  | 16         | .322                   | .89      | .39                  | 16.23    |
| 247          | 21.59                  | 10.96                | 120        | .535                   | .74      | .81                  | 35.26    |
| 248          | 64.81                  | 12.32                | 155        | .60                    | .92      | .36                  | 42.12    |
| 249          | 10.71                  | 11.35                | 5          | .47                    | .92      | .39                  | 29.1     |
| 250          | 9.50                   | 9.88                 | 40         | .571                   | .92      | .40                  | 25.23    |
| 251          | 0                      | 6.74                 | 5          | 0                      | .86      | .81                  | 10.77    |
| 252          | 0                      | 6.10                 | 20         | 0                      | .82      | .82                  | 16.07    |
| 253          | 0                      | 10.41                | 46         | 0                      | .81      | .83                  | 21.00    |
| 253          | 0                      | 11.08                | 116        | 0                      | .81      | .85                  | 21.00    |
| 254          | 0                      | 14.21                | 88         | 0                      | .78      | .80                  | 24.96    |
| 255          | 0                      | 23.10                | 160        | 0                      | .80      | .82                  | 31.28    |
| 256          | 0                      | 32.30                | 222        | 0                      | .81      | .84                  | 36.27    |

# THREAT DATA SUMMARY

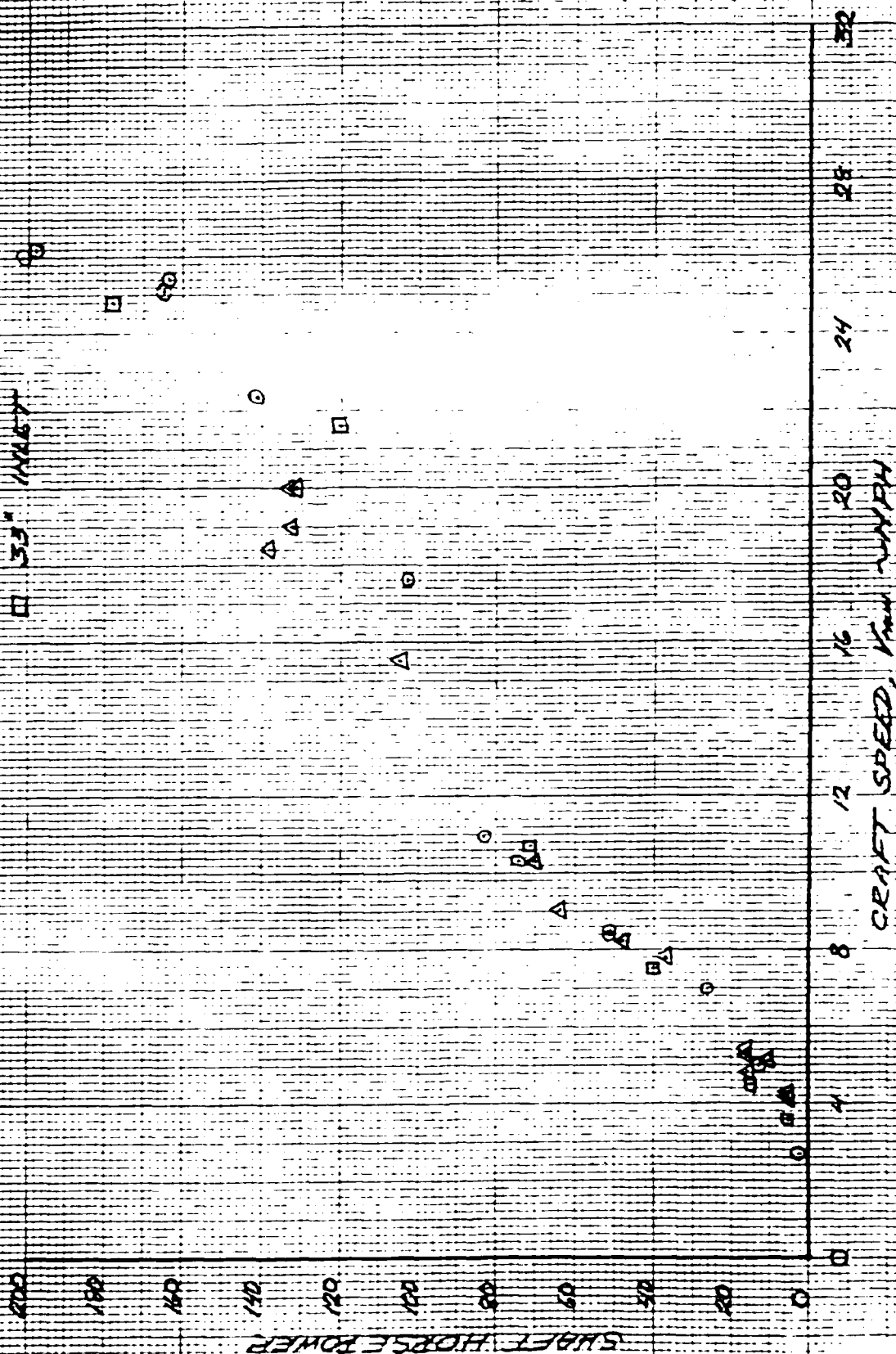
15 JUL 1962

19.5" MFT  
22" MFT  
33" MFT



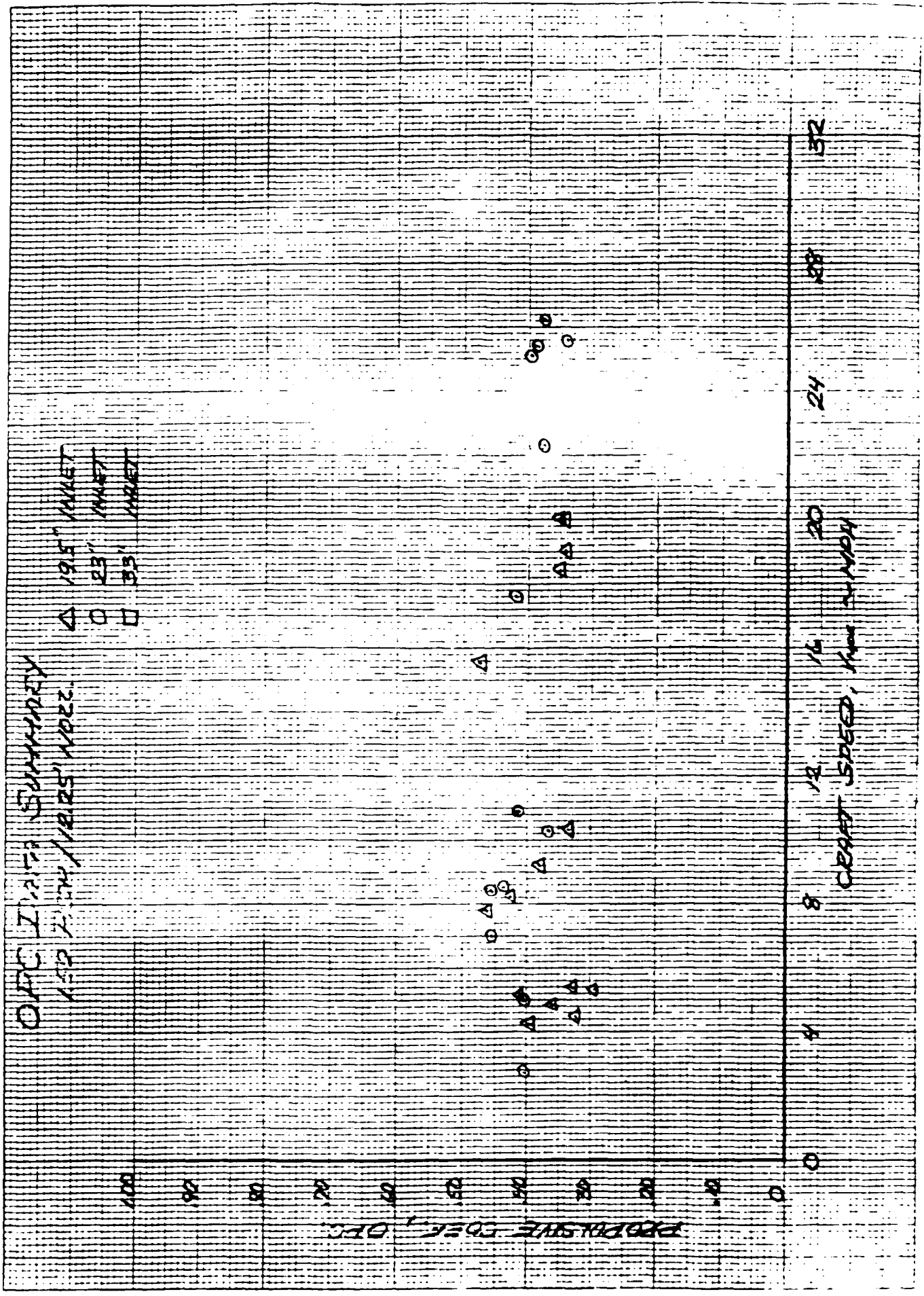
SHIP DATA SUMMARY  
 LOP 10/12/51 NO. 22.

△ 19.5' INLET  
 ○ 23' INLET  
 □ 33' INLET



OPC I 12151 SUMMARY  
 2204 5515, 1002  
 150 2 104 10125, 1002

Δ 19.5" MKET  
 ○ 23" MKET  
 □ 33" MKET

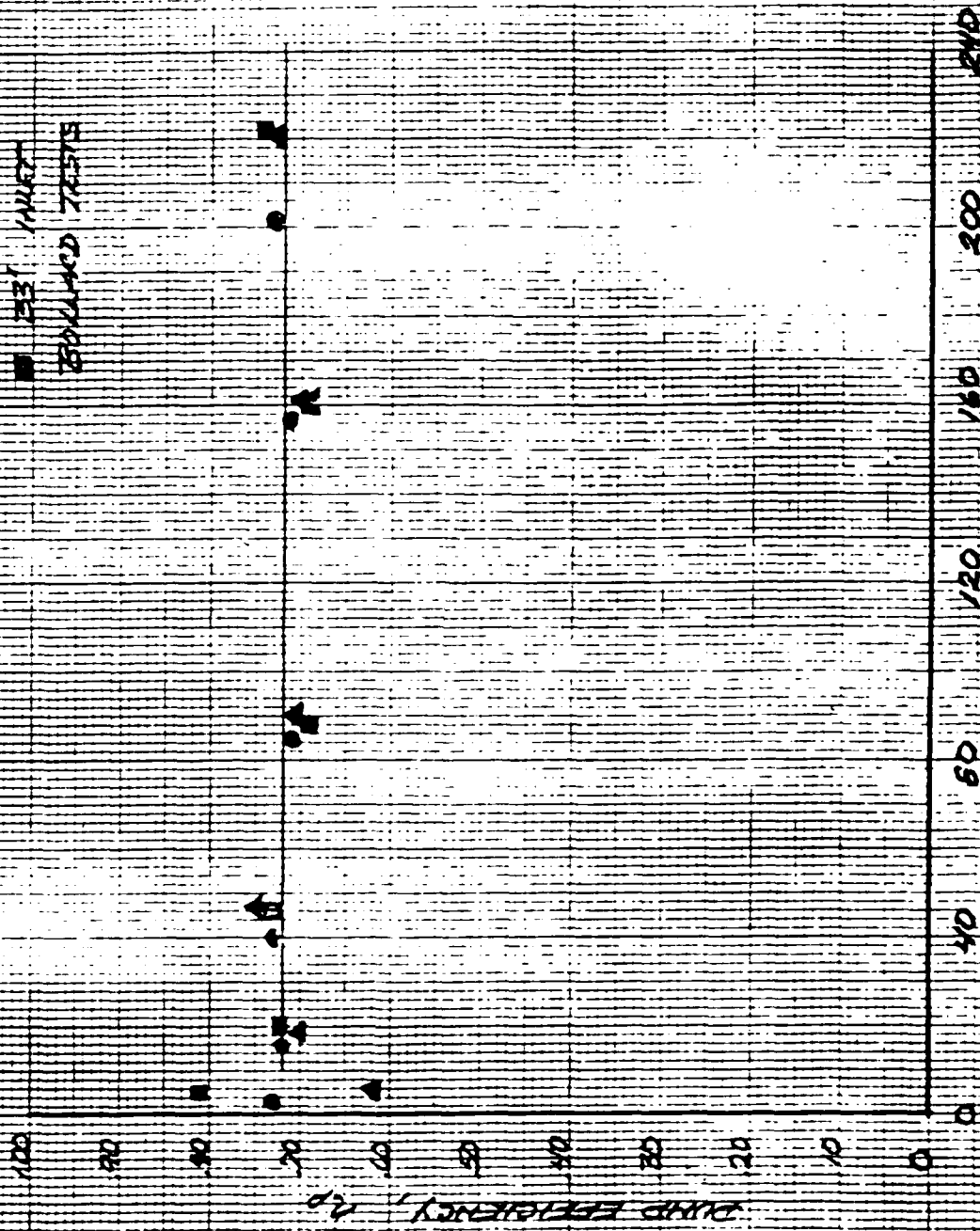


# PUMP EFFICIENCY DATA SUMMARY

1.50 PPM / 13.50' H<sub>2</sub>O

- ▲ 13.5' H<sub>2</sub>O
- 23' H<sub>2</sub>O
- 33' H<sub>2</sub>O

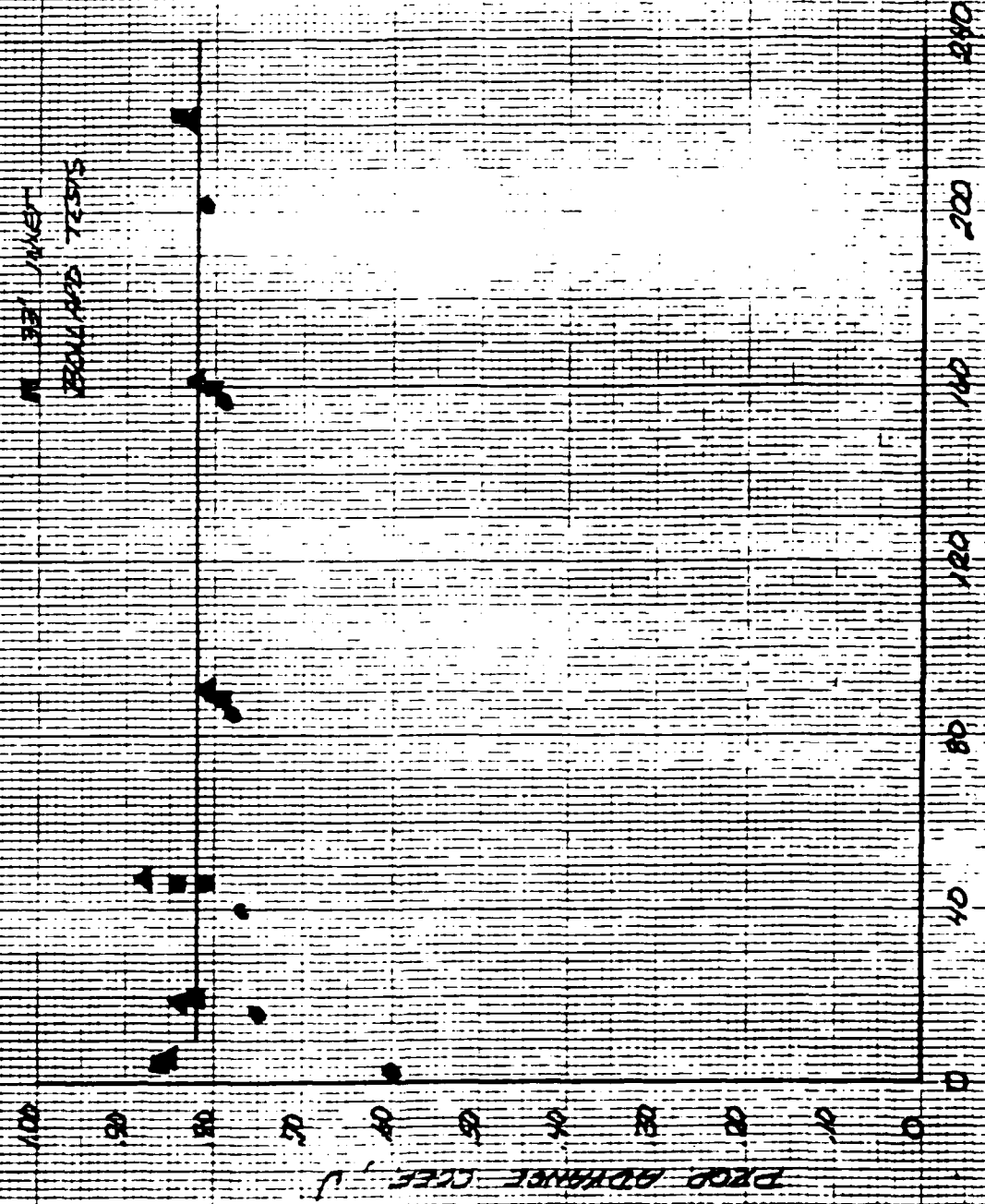
BACKWARD TESTS



SHAFT HORSEPOWER, SHP

PROP ADVANCE COEF. DATA SUMMARY  
 150 RPM / 1000' W022  
 185' W022  
 213' W022  
 233' W022

ROLL AND TESTS



# STATIC THRUST COMPARISON

## 1.50 Prop.

$$T_s = T_o - R_n$$

$$T_o = \rho Q (V_o - V_i)$$

$$V_o = \frac{Q}{A_o} = \frac{Q}{.8180} = 1.2224 Q$$

$$V_i = 0$$

$$T_o = 1.74 Q (1.2224 Q - 0) = 2.1215 Q^2$$

$$R_n = .1639 Q^2$$

$$T_s = 2.1215 Q^2 - .1639 Q^2 = 2.0076 Q^2$$

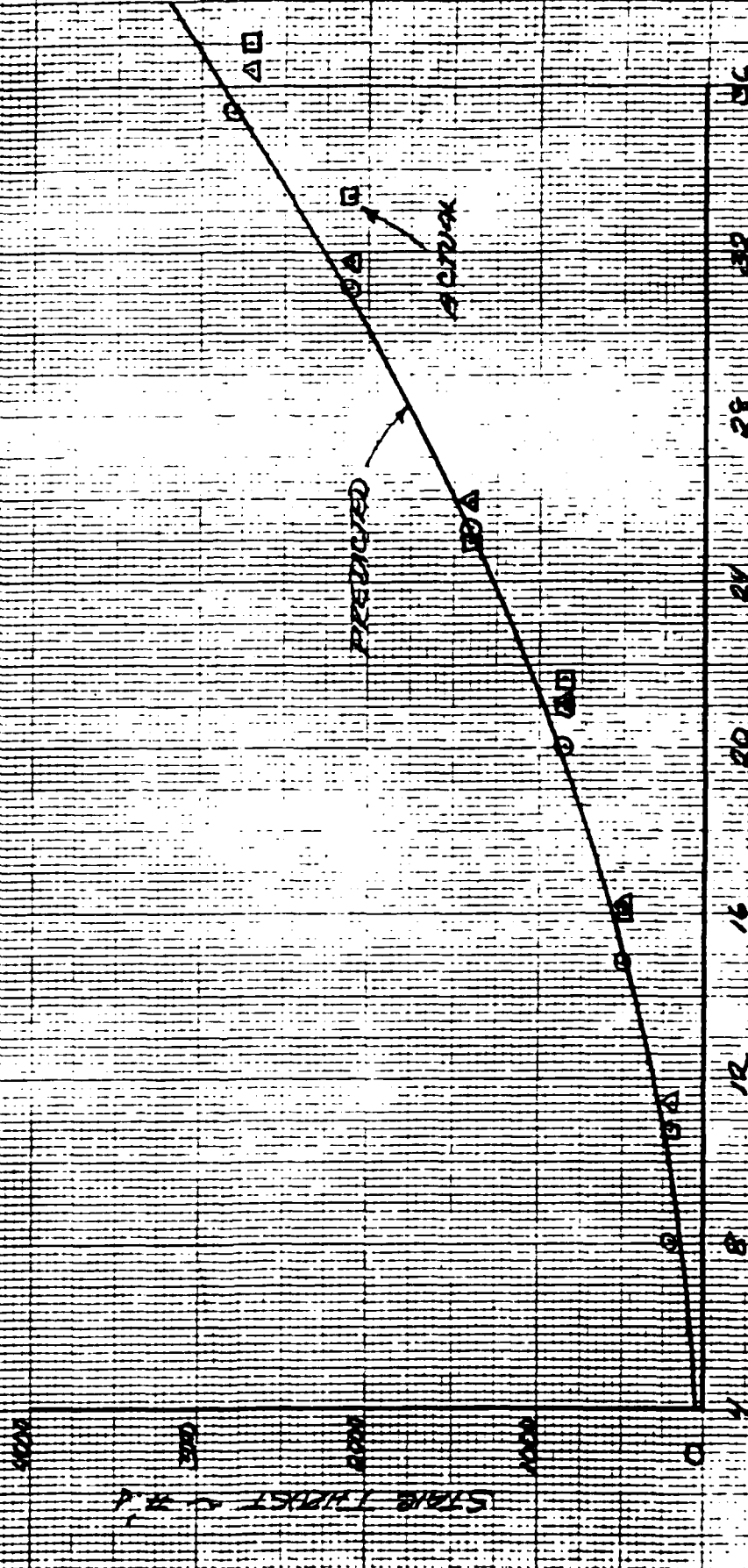
(per lb. sec)

| Run # | Nozz   | Inlet | Q     | $\frac{P_{act}}{T_s}$ | $\frac{A_{act}}{T_s}$ |
|-------|--------|-------|-------|-----------------------|-----------------------|
| 212   | 12.25" | 23"   | 8.07  | 144                   | 200                   |
| 213   |        | 0     | 14.06 | 481                   | 500                   |
| 214   |        |       | 20.04 | 887                   | 850                   |
| 215   |        |       | 25.30 | 1413                  | 1400                  |
| 216   |        |       | 31.10 | 2135                  | 2200                  |
| 217   |        |       | 35.38 | 2763                  | 2600                  |
| 226   | 12.25" | 19.5" | 11.41 | 287                   | 200                   |
| 229   |        | 0     | 16.85 | 583                   | 500                   |
| 230   |        |       | 22.76 | 1144                  | 850                   |
| 231   |        |       | 26.04 | 1497                  | 1400                  |
| 232   |        |       | 31.57 | 2228                  | 2100                  |
| 233   |        |       | 36.35 | 2917                  | 2700                  |
| 251   | 12.25" | 33"   | 10.77 | 286                   | 200                   |
| 252   |        | 0     | 16.07 | 570                   | 500                   |
| 253   |        |       | 21.00 | 974                   | 850                   |
| 254   |        |       | 24.96 | 1375                  | 1400                  |
| 255   |        |       | 31.28 | 2160                  | 2100                  |
| 256   |        |       | 36.79 | 3021                  | 2700                  |

# STATIC THRUST COMPARISON

150 20 40 120 250 400

Δ 19.5" INLET  
 ○ 23" INLET  
 □ 33" INLET



# INLET LOSS COMPARISON (BOWARD TEST)

1.50 PROD. / 12.25 NOZZ / 23" INLET

$$H_{L_s} = H_0 - H_{L_I} - \frac{V_I^2}{2g}$$

$$H_0 = 0$$

$$H_{L_I} = .00287 Q^2$$

$$\frac{V_I^2}{2g} = \left( \frac{Q}{1.0435} \right)^2 \frac{1}{2(32.2)} = .0143 Q^2$$

$$H_{L_s} = 0 - .00287 Q^2 - .0143 Q^2$$

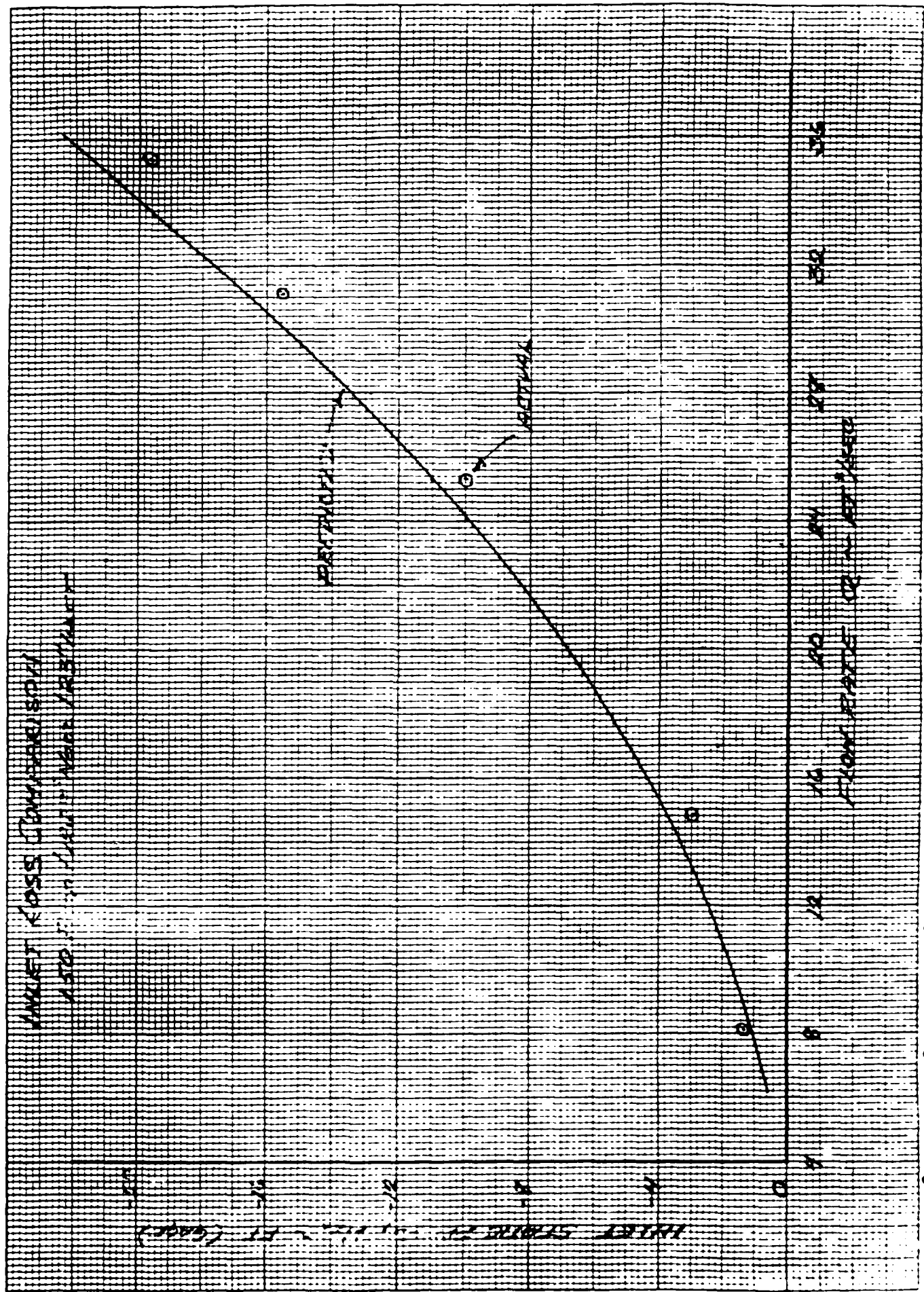
$$H_{L_s} = -.01719 Q^2$$

(PREDICTED)

$$H_{L_s} = \text{ADEI} \left( \frac{144}{62.5} \right) = 2.328 \text{ F.T.}$$

(ACTUAL)

| <u>P<sub>01</sub></u> | <u>Q</u> | <u>P<sub>01</sub></u><br><u>H<sub>L_s</sub></u> | <u>ACT.</u><br><u>H<sub>L_s</sub></u> | <u>ACT.</u><br><u>H<sub>L_s</sub></u> |
|-----------------------|----------|-------------------------------------------------|---------------------------------------|---------------------------------------|
| 212                   | 8.07     | -1.12                                           | -.96                                  | -1.29                                 |
| 213                   | 14.16    | -3.24                                           | -1.28                                 | -2.95                                 |
| 214                   | 20.24    | -6.90                                           | -1.17                                 | -2.77                                 |
| 215                   | 25.30    | -11.00                                          | -4.31                                 | -2.95                                 |
| 216                   | 31.10    | -16.63                                          | -6.22                                 | -5.5                                  |
| 217                   | 35.38    | -21.52                                          | -8.4                                  | -9.52                                 |



# INLET LOSS COMPARISON (BOLLARD TEST)

1.50 PAPP. / 12.25 NOZZ. / 19.5" INLET

$$H_{fs} = H_0 - H_{L1} - \frac{V_I^2}{2g}$$

$$H_0 = 0$$

$$H_{L1} = .003755 Q^2$$

$$\frac{V_I^2}{2g} = \left( \frac{Q}{1.043} \right)^2 \frac{1}{2(32.2)} = .0143 Q^2$$

$$H_{fs} = 0 - .003755 Q^2 - .0143 Q^2$$

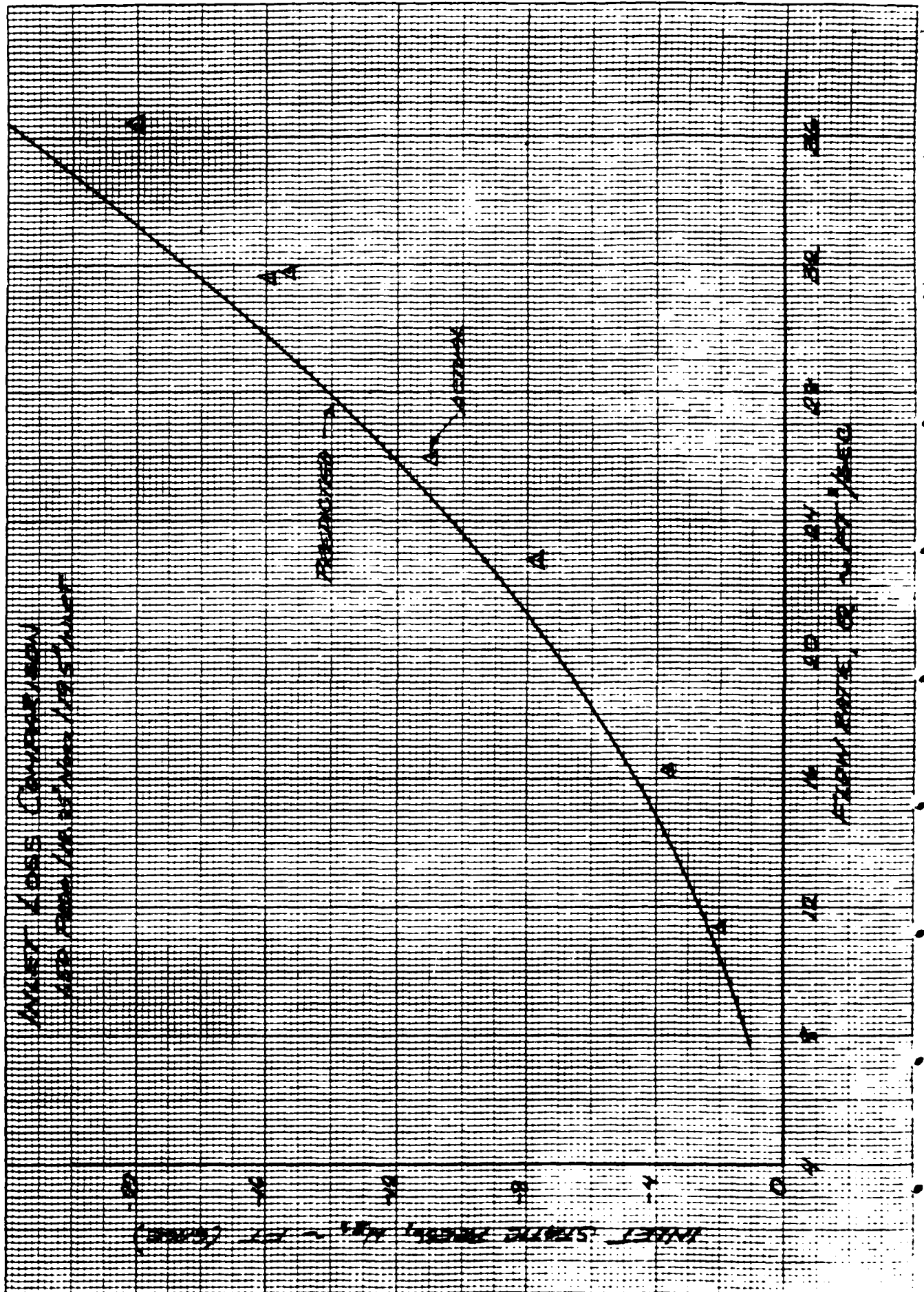
$$H_{fs} = -.018055 Q^2$$

(PREDICTED)

$$H_{fs} = APSI \left( \frac{1.75}{61.1} \right) = 2.306 APSI$$

(ACTUAL)

| <u>R<sub>W</sub></u> | <u>Q</u> | <u>PRED</u><br><u>H<sub>fs</sub></u> | <u>APSI</u> | <u>ACTUAL</u><br><u>H<sub>fs</sub></u> |
|----------------------|----------|--------------------------------------|-------------|----------------------------------------|
| 228                  | 11.41    | -2.35                                | -.86        | -1.98                                  |
| 229                  | 16.25    | -4.77                                | -1.56       | -3.60                                  |
| 231                  | 22.26    | -9.35                                | -2.57       | -6.62                                  |
| 231                  | 26.54    | -12.24                               | -4.26       | -10.55                                 |
| 232                  | 31.77    | -18.22                               | -6.65       | -15.35                                 |
| 232                  | 31.65    | -18.19                               | -6.68       | -15.68                                 |
| 233                  | 36.25    | -23.86                               | -8.57       | -20.01                                 |



# INLET LOSS COMPARISON

1.57 PROP / 12.25 NOZZ / 33" INLET

$$H_{T_s} = H_0 - H_{L_s} - \frac{V_s^2}{2g}$$

$$H_0 = 0$$

$$H_{L_s} = .005725 Q^2$$

$$\frac{V_s^2}{2g} = \frac{Q^2}{1.43^5} \cdot \frac{1}{2 \cdot 32.2} = .01337 Q^2$$

$$H_{T_s} = 0 - .005725 Q^2 - .01337 Q^2 = -.0191 Q^2$$

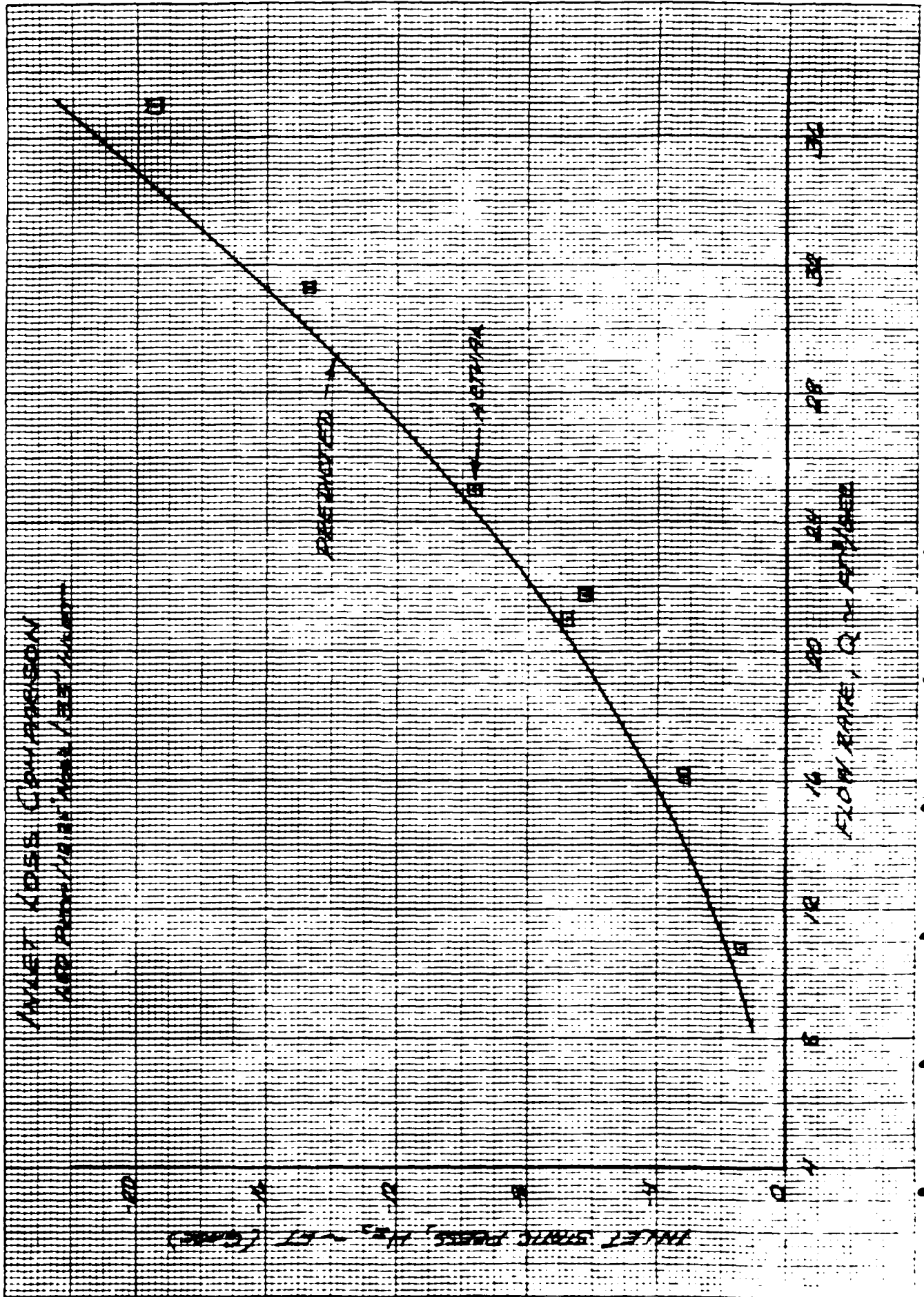
$$H_{L_s} = -.01337 Q^2$$

(Pressure)

$$H_{T_s} = APSI \left( \frac{14.7}{62.4} \right) = 2.302 APSI$$

(Head)

| <u>Psi</u> | <u>Q</u> | <u>Psi</u><br><u>H<sub>Ls</sub></u> | <u>APSI</u><br><u>H<sub>Ts</sub></u> | <u>Head</u><br><u>H<sub>Ts</sub></u> |
|------------|----------|-------------------------------------|--------------------------------------|--------------------------------------|
| 251        | 10.77    | -1.90                               | -1.10                                | -1.36                                |
| 252        | 13.77    | -4.22                               | -1.38                                | -3.18                                |
| 253        | 21.77    | -12.70                              | -2.94                                | -6.77                                |
| 253        | 21.77    | -12.70                              | -2.94                                | -6.23                                |
| 251        | 24.77    | -15.77                              | -4.17                                | 9.67                                 |
| 255        | 31.27    | -19.77                              | -6.37                                | 14.70                                |
| 256        | 36.99    | -22.35                              | -8.42                                | -17.12                               |



# INLET PRESSURE RECOVERY COMPARISON

1.5" ID / 12.25" NO. 123" INLET 0

$$h_o = h_{t, \text{SPEED TESTS}} - h_{t, \text{BOILING TESTS}}$$

$$h_{t, \text{SPEED TESTS}} = h_{t, \text{SPEED TESTS}} \left( \frac{V}{V_0} \right)^2 = 2.308 \text{ FPS}$$

$$h_{t, \text{BOILING TESTS}} = -0.01719 Q^2$$

(FROM INLET LOSS TESTS)

$$h_o = 2.308 \text{ (FPS)} + 0.01719 Q^2$$

(Final)

| <u>Run</u> | <u>Q</u> | <u>h</u> | <u>h<sub>t</sub></u> | <u>h<sub>o</sub></u> |   |
|------------|----------|----------|----------------------|----------------------|---|
| 201        | 16.25    | 1.12     | +2.31                | 9.4                  | x |
| 202        | 32.25    | 2.52     | +2.31                | 11.70                |   |
| 203        | 48.25    | 3.92     | +2.31                | 14.09                |   |
| 204        | 64.25    | 5.32     | +2.31                | 16.48                |   |
| 205        | 80.25    | 6.72     | +2.31                | 18.87                |   |
| 206        | 96.25    | 8.12     | +2.31                | 21.26                | x |
| 207        | 112.25   | 9.52     | +2.31                | 23.65                | x |
| 208        | 128.25   | 10.92    | +2.31                | 26.04                |   |
| 209        | 144.25   | 12.32    | +2.31                | 28.43                |   |
| 210        | 160.25   | 13.72    | +2.31                | 30.82                |   |
| 211        | 176.25   | 15.12    | +2.31                | 33.21                |   |
| 218        | 7.25     | 3.12     | +2.31                | 4.8                  |   |
| 219        | 32.25    | 12.32    | +2.31                | 19.9                 |   |
| 220        | 41.00    | 19.62    | +2.31                | 27.3                 |   |

$$h_o = \frac{V_o^2}{2g} = \frac{V_o^2}{2(32.2)}$$

(Final)

$$\frac{V_o}{1}$$

|    |       |
|----|-------|
| 10 | 1.55  |
| 20 | 6.20  |
| 30 | 13.75 |
| 40 | 24.37 |

# INLET PRESSURE RECOVERY Comparison

150 PPOD / 12.25" Nozzle / 7.5" Inlet     Δ

$$H_o = H_{t, \text{SPEED TEST}} - H_{t, \text{ZEPHUS TEST}}$$

$$H_{t, \text{SPEED TEST}} = AFS \left( \frac{V_o}{100} \right)^2 = 2308 AFS$$

$$H_{t, \text{ZEPHUS TEST}} = .018055 Q^2$$

(From the test data)

$$H_o = 2308 AFS + .018055 Q^2$$

(Actual)

| <u>RUN #</u> | <u>Q</u> | <u>V<sub>o</sub></u> | <u>AFS</u> | <u>Actual H<sub>o</sub></u> |
|--------------|----------|----------------------|------------|-----------------------------|
| 221          | 10.37    | 6.77                 | -1.36      | 1.11                        |
| 222          | 16.06    | 9.97                 | -1.89      | 2.10                        |
| 223          | 15.54    | 9.54                 | -1.80      | 2.08                        |
| 224          | 33.21    | 22.77                | -3.74      | 13.71                       |
| 225          | 31.78    | 20.44                | -3.52      | 12.06                       |
| 226          | 26.88    | 15.92                | -2.55      | 6.19                        |
| 227          | 24.77    | 12.00                | -2.53      | 3.85                        |
| 228          | 11.71    | 6.20                 | -1.11      | 1.39                        |
| 229          | 16.32    | 9.13                 | -1.87      | 3.05                        |
| 230          | 34.70    | 27.08                | -3.50      | 23                          |
| 231          | 30.36    | 13.32                | -2.50      | 5.40                        |
| 232          | 36.1     | 37.32                | -5.70      | 11.44                       |
| 233          | 38.1     | 22.37                | -3.07      | 3.42                        |
| 234          | 21.2     | 27.1                 | -3.78      | 12.9                        |
| 235          | 14.27    | 3.27                 | -3.1       | 1.7                         |
| 236          | 23.7     | 1.1                  | -2.5       | 1.5                         |
| 243          | 19.97    | 9.72                 | -1.25      | 1.1                         |

$$H_o = \frac{V_o^2}{2g} \left( 1 - \frac{A_o}{A_t} \right)^2 \left( \frac{1}{\gamma} \right)$$

| <u>V<sub>o</sub></u> | <u>H<sub>o</sub></u> |
|----------------------|----------------------|
| 10                   | 1.15                 |
| 20                   | 6.20                 |
| 30                   | 13.9                 |
| 40                   | 24.15                |

# INLET PRESSURE RECEIVER, COMPARISON

1.50 PROP / 12.25" NOZZ / 33" INLET □

$$H_0 = H_{H_2S} - H_{H_2O}$$

SPEED      EXCESS  
TEST      TEST

$$H_{H_2S} = H_{PS} \left( \frac{1}{1.43} \right) = 2356 \text{ PPSI}$$

$$H_{H_2O} = -.016337 Q^2$$

(FROM AIR - LIQUID COMPRESSOR)

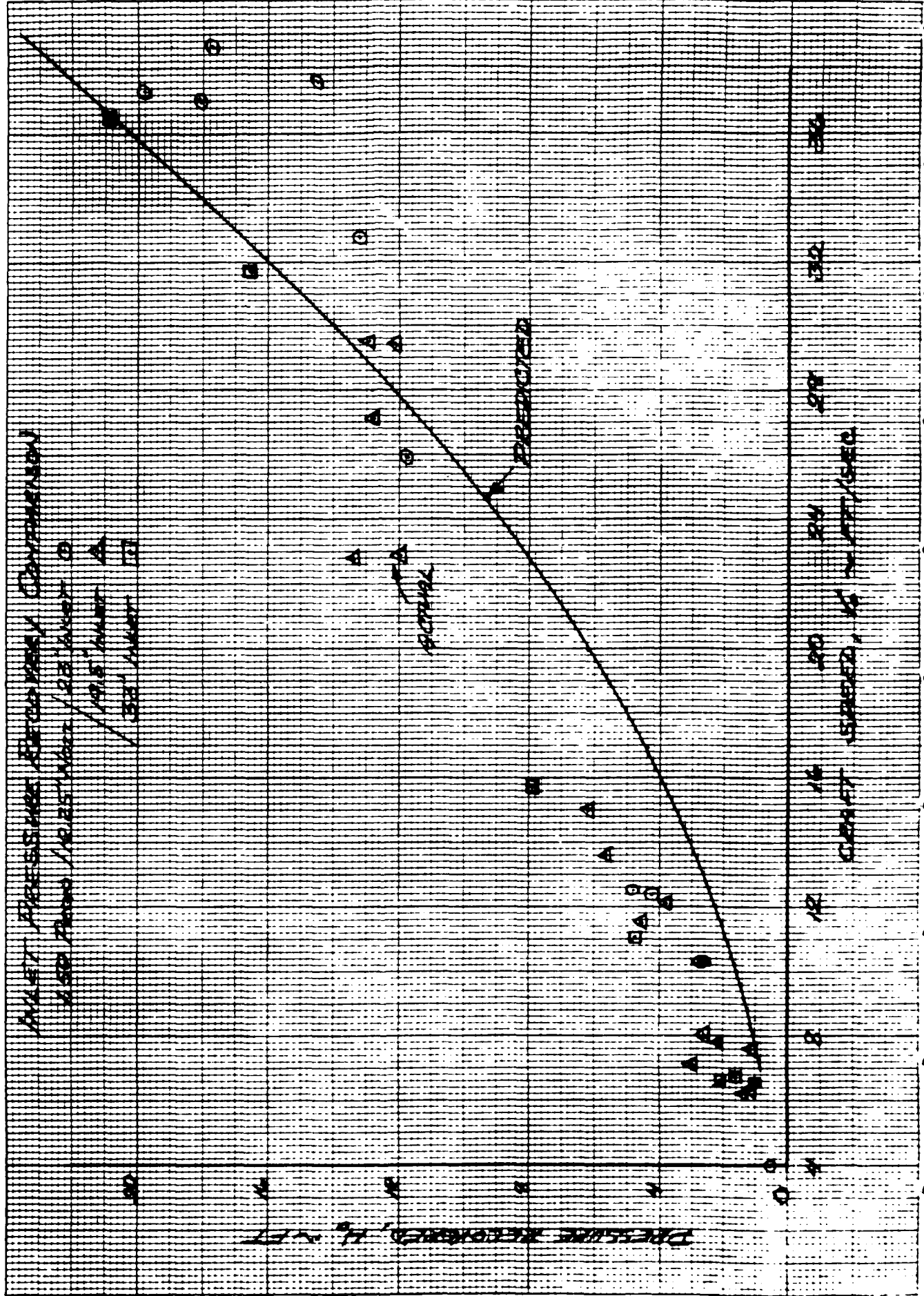
$$H_0 = 2356 \text{ PPSI} + .016337 Q^2 \quad (\text{ACTUAL})$$

| <u>PSI*</u> | <u>Q</u> | <u>1/3</u> | <u>H<sub>PS</sub></u> | <u>A<sub>area</sub> / H<sub>0</sub></u> |
|-------------|----------|------------|-----------------------|-----------------------------------------|
| 244         | 12.25    | 5          | -1.31                 | .95                                     |
| 245         | 12.25    | 6.25       | -1.16                 | 2.07                                    |
| 246         | 12.25    | 6.25       | -1.14                 | 1.58                                    |
| 247         | 33.1     | 7          | -3                    | 16.79                                   |
| 248         | 40.2     | 7.75       | -3.10                 | 20.93                                   |
| 249         | 52.5     | 8          | -3.24                 | 2.90                                    |
| 250         | 55.2     | 8.52       | -3.52                 | 4.75                                    |

$$H_0 = \frac{10}{13} \left( \frac{1}{1.43} \right) \left( \frac{1}{1.43} \right) \quad (\text{PREDICTED})$$

$$\frac{P_{PS}}{H_0}$$

|    |       |
|----|-------|
| 10 | 1.55  |
| 20 | 6.20  |
| 30 | 13.95 |
| 40 | 24.80 |



# REQUIRED PUMP HEAD COMPARISON

1.50 PROP. / 12.25" NOZZ. / 43" INLET

$$H_p = .030761 Q^2 - .0155 V_o^2$$

(PRELIM)

| <u>RUN</u> | <u>Q</u> | <u>V<sub>o</sub></u> | <u>Req<br/>H<sub>p</sub></u> | <u>Act<br/>H<sub>p</sub></u> |
|------------|----------|----------------------|------------------------------|------------------------------|
| 201        | 16.06    | 7.28                 | 2.11                         | 4.36                         |
| 202        | 32.95    | 25.67                | 23.02                        | 20.68                        |
| 203        | 40.35    | 36.74                | 24.93                        | 26.70                        |
| 204        | 40.27    | 32.28                | 28.34                        | 27.66                        |
| 205        | 42.05    | 38.56                | 31.35                        | 29.43                        |
| 206        | 27.48    | 15.08                | 19.70                        | 16.95                        |
| 207        | 29.60    | 16.07                | 23.31                        | 18.75                        |
| 208        | 26.70    | 12.48                | 18.70                        | 11.50                        |
| 209        | 26.56    | 12.35                | 19.34                        | 11.20                        |
| 210        | 21.02    | 10.29                | 11.95                        | 6.90                         |
| 211        | 20.99    | 10.33                | 11.90                        | 6.78                         |
| 212        | 8.07     | 0                    | 2.00                         | 2.48                         |
| 213        | 14.76    | 0                    | 6.70                         | 6.75                         |
| 214        | 20.54    | 0                    | 12.35                        | 12.78                        |
| 215        | 25.30    | 0                    | 19.69                        | 20.74                        |
| 216        | 31.10    | 0                    | 29.75                        | 31.33                        |
| 217        | 35.58    | 0                    | 38.50                        | 39.20                        |
| 218        | 9.25     | 3.95                 | 2.39                         | 2.08                         |
| 219        | 36.74    | 32.7                 | 25.30                        | 24.86                        |
| 220        | 41.00    | 39.66                | 29.77                        | 28.62                        |

# REQUIRED PUMP HEAD COMPARISON

1.50 PWD / 12.25" NOZZ. / 19.5" INLET

$$H_p = .031767 Q^2 - .0155 V_o^2$$

(FEED CRED)

| <u>ROW#</u> | <u>Q</u> | <u>V<sub>o</sub></u> | <u>FRSD<br/>HP</u> | <u>1-2-5<br/>HP</u> |
|-------------|----------|----------------------|--------------------|---------------------|
| 221         | 10.37    | 6.29                 | 2.60               | 2.93                |
| 222         | 16.06    | 7.97                 | 7.21               | 7.27                |
| 223         | 15.11    | 7.84                 | 6.72               | 7.33                |
| 224         | 33.1     | 22.90                | 28.18              | 25.48               |
| 225         | 34.36    | 29.44                | 24.11              | 25.21               |
| 226         | 26.8     | 15.02                | 18.28              | 17.32               |
| 227         | 23.39    | 12.10                | 15.11              | 15.22               |
| 228         | 11.41    | 0                    | 4.14               | 3.01                |
| 229         | 16.25    | 0                    | 8.39               | 7.10                |
| 230         | 22.76    | 0                    | 16.46              | 13.55               |
| 231         | 26.24    | 0                    | 21.54              | 21.58               |
| 232         | 31.77    | 0                    | 32.06              | 30.90               |
| 232         | 31.65    | 0                    | 31.82              | 31.68               |
| 233         | 36.35    | 0                    | 41.97              | 38.67               |
| 234         | 11.71    | 0.00                 | 3.76               | 3.04                |
| 235         | 16.82    | 0.13                 | 8.20               | 6.93                |
| 236         | 34.20    | 27.08                | 25.79              | 26.33               |
| 237         | 30.36    | 13.32                | 26.53              | 17.76               |
| 237         | 30.21    | 37.32                | 21.67              | 28.78               |
| 237         | 33.74    | 20.60                | 28.11              | 21.45               |
| 237         | 34.62    | 29.47                | 24.61              | 25.55               |
| 237         | 26.67    | 13.60                | 19.72              | 15.44               |
| 237         | 23.74    | 11.45                | 16.16              | 10.23               |
| 238         | 14.77    | 2.56                 | 6.23               | 4.59                |

# REQUIRED PUMP HEAD COMPARISON

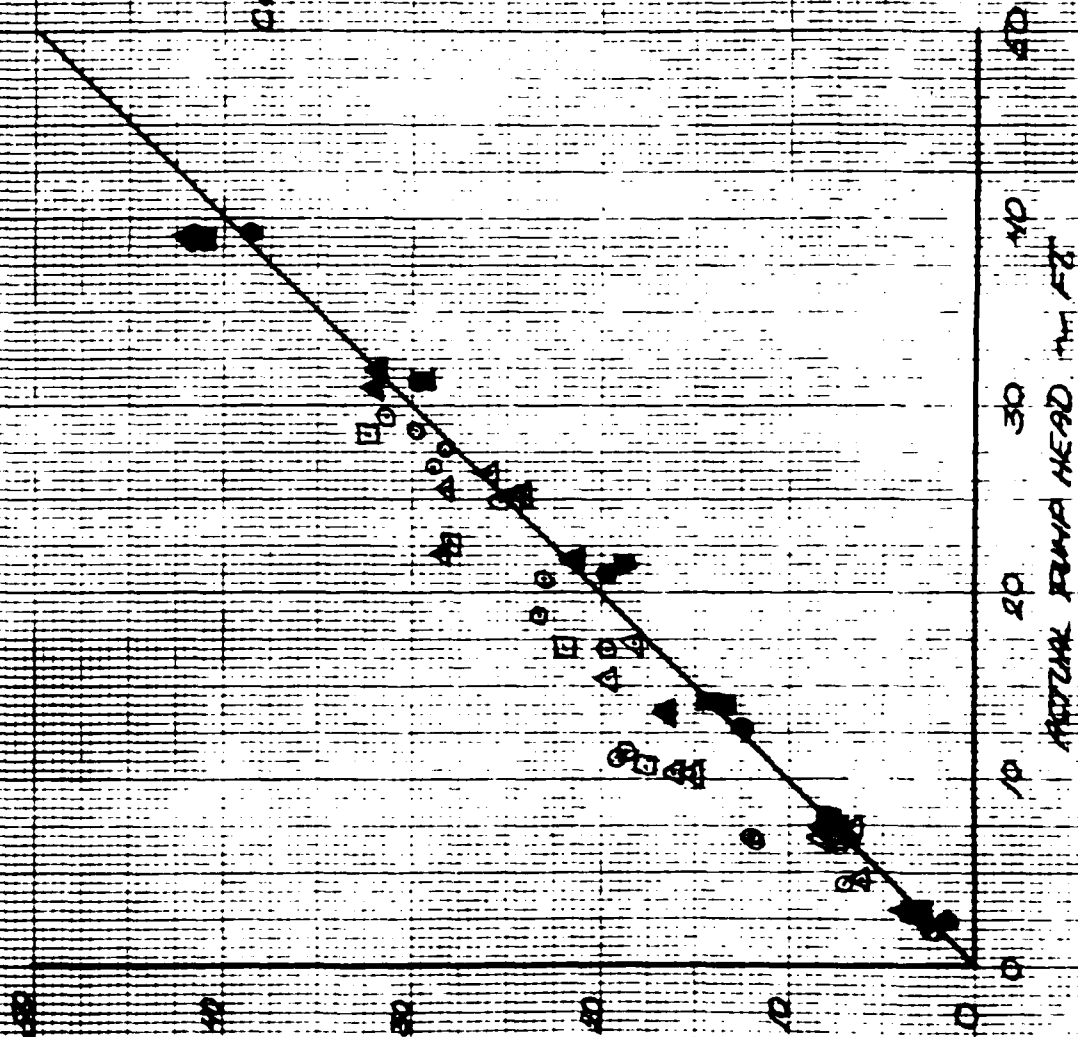
1.50 PROP. / 12.25" NOZ. / 33' INLET

$$H_p = .030049 Q^2 - V_o^2$$

(PREDICTED)

| <u>Flow</u> | <u>Q</u> | <u>V<sub>o</sub></u> | <u>Pred<br/>H<sub>p</sub></u> | <u>Act<br/>H<sub>p</sub></u> |
|-------------|----------|----------------------|-------------------------------|------------------------------|
| 244         | 12.02    | 5.31                 | 3.90                          | 3.05                         |
| 245         | 12.05    | 6.62                 | 8.06                          | 6.59                         |
| 246         | 16.27    | 6.69                 | 9.26                          | 6.68                         |
| 247         | 38.20    | 31.74                | 27.91                         | 22.65                        |
| 248         | 42.12    | 36.74                | 32.39                         | 24.41                        |
| 249         | 29.27    | 15.74                | 21.90                         | 16.95                        |
| 250         | 25.43    | 11.02                | 17.55                         | 10.59                        |
| 251         | 10.77    | 0                    | 3.49                          | 3.42                         |
| 252         | 16.07    | 0                    | 9.76                          | 7.84                         |
| 253         | 21.00    | 0                    | 13.25                         | 14.09                        |
| 253         | 21.56    | 0                    | 14.10                         | 14.15                        |
| 254         | 24.96    | 0                    | 18.72                         | 21.60                        |
| 255         | 31.28    | 0                    | 29.40                         | 31.34                        |
| 256         | 36.79    | 0                    | 41.11                         | 39.42                        |

PUMP HEAD COMPARISON  
 1500 RPM / 18.25 MARE



STILL ON THE SAME SIDE OF THE ROAD  
 1500 RPM / 18.25 MARE  
 1500 RPM / 18.25 MARE  
 1500 RPM / 18.25 MARE

# SHP COMPARISON

$$SHP = .1577 Q Hp$$

(Predicted)

| <u>RW</u> | <u>PROP</u> | <u>NOZZ</u> | <u>INLET</u> | <u>Q</u> | <u>PRED HP</u> | <u>PRED SHP</u> | <u>ACTUAL SHP</u> |
|-----------|-------------|-------------|--------------|----------|----------------|-----------------|-------------------|
| 201       | 1.50        | 12.25       | 23"          | 16.06    | 2.11           | 18              | 13                |
| 202       |             |             |              | 32.95    | 23.02          | 120             | 103               |
| 203       |             |             |              | 40.35    | 28.93          | 184             | 155               |
| 204       |             |             |              | 40.27    | 28.34          | 180             | 144               |
| 205       |             |             |              | 42.05    | 31.35          | 208             | 195               |
| 206       |             |             |              | 27.48    | 19.20          | 95              | 74                |
| 207       |             |             |              | 29.80    | 23.31          | 110             | 83                |
| 208       |             |             |              | 26.20    | 16.20          | 77              | 57                |
| 209       |             |             |              | 26.56    | 19.34          | 91              | 57                |
| 210       |             |             |              | 21.02    | 11.95          | 40              | 26                |
| 211       |             |             |              | 20.99    | 11.90          | 39              | 26                |
| 212       |             |             |              | 8.07     | 2.00           | 3               | 3                 |
| 213       |             |             |              | 14.76    | 6.70           | 16              | 16                |
| 214       |             |             |              | 20.04    | 12.35          | 39              | 40                |
| 215       |             |             |              | 25.30    | 19.69          | 79              | 85                |
| 216       |             |             |              | 31.10    | 29.25          | 146             | 157               |
| 217       |             |             |              | 35.38    | 36.50          | 215             | 215               |
| 218       |             |             |              | 9.25     | 2.39           | 4               | 2                 |
| 219       |             |             |              | 36.74    | 25.20          | 147             | 141               |
| 220       |             |             |              | 41.00    | 29.77          | 192             | 201               |
| 221       | 1.50        | 12.25       | 19.5"        | 10.37    | 2.80           | 5               | 5                 |
| 222       |             |             |              | 16.06    | 2.21           | 18              | 12                |
| 223       |             |             |              | 15.54    | 6.72           | 16              | -                 |
| 224       |             |             |              | 33.81    | 28.18          | 150             | 122               |
| 225       |             |             |              | 34.38    | 24.11          | 131             | 131               |
| 226       |             |             |              | 26.18    | 18.28          | 75              | 70                |
| 227       |             |             |              | 23.39    | 15.11          | 56              | 31                |
| 228       |             |             |              | 11.41    | 4.4            | 7               | -                 |
| 229       |             |             |              | 16.25    | 8.39           | 22              | 19                |
| 230       |             |             |              | 22.76    | 13.10          | 59              | 47                |
| 231       |             |             |              | 26.04    | 21.54          | 98              | 70                |
| 232       |             |             |              | 31.77    | 32.26          | 161             | 161               |
| 232       |             |             |              | 31.65    | 31.82          | 159             | 161               |
| 233       |             |             |              | 36.35    | 41.97          | 241             | 221               |
| 234       |             |             |              | 11.71    | 3.76           | 7               | 5                 |
| 235       |             |             |              | 16.82    | 8.20           | 22              | 16                |
| 236       |             |             |              | 34.20    | 25.79          | 139             | 135               |
| 237       |             |             |              | 30.36    | 26.53          | 127             | 2                 |
| 238       |             |             |              | 36.71    | 21.69          | 126             | 192               |
| 239       |             |             |              | 33.74    | 28.11          | 150             | 155               |
| 240       |             |             |              | 34.62    | 24.61          | 134             | 133               |
| 241       |             |             |              | 26.67    | 19.72          | 83              | 64                |
| 242       |             |             |              | 23.94    | 16.16          | 61              | 37                |
| 243       |             |             |              | 14.97    | 6.23           | 15              | 10                |

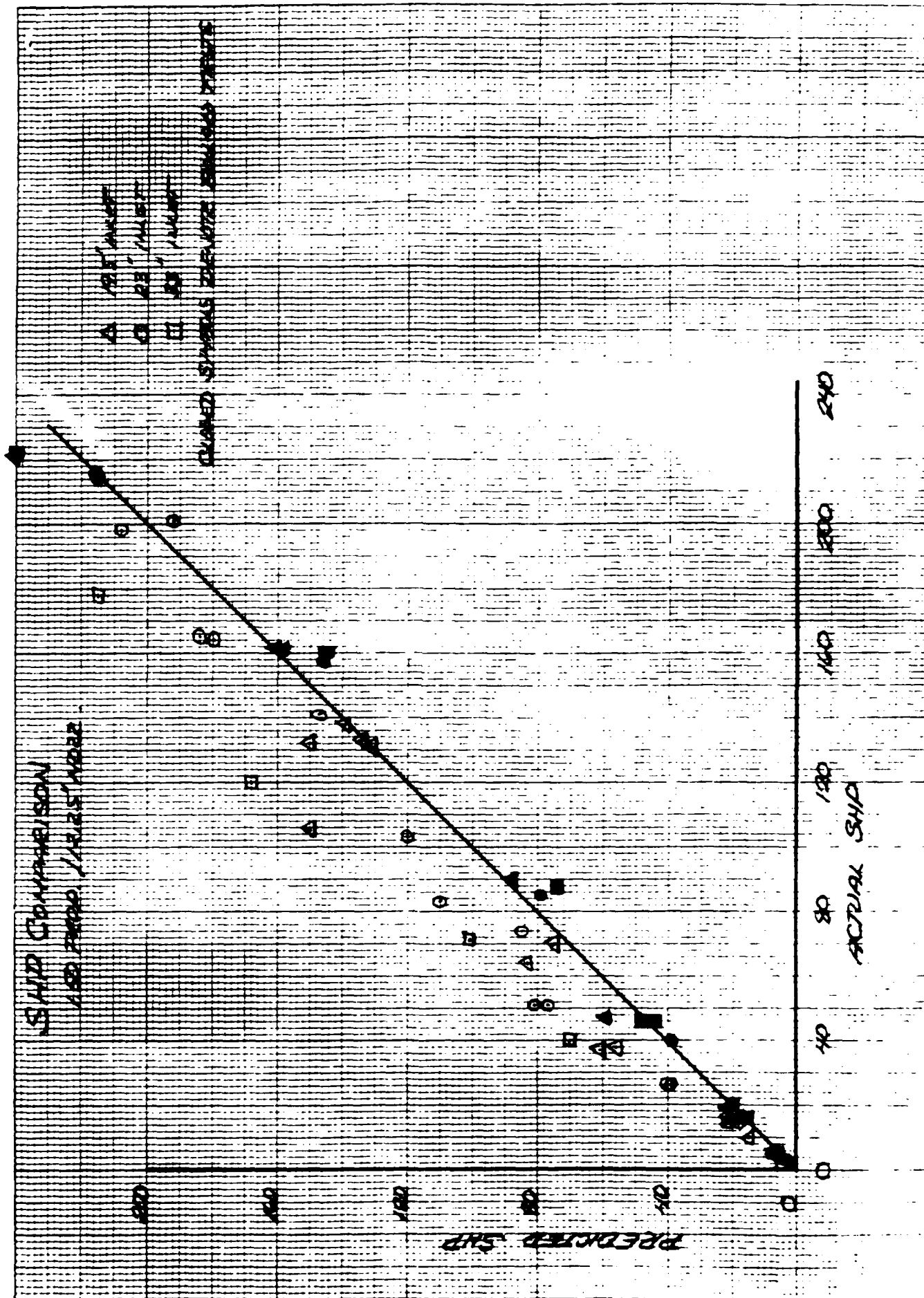
Bouquet Tests

Bouquet Tests

# SHP COMPARISON

| <u>RW</u> | <u>Pop</u> | <u>No.2.</u> | <u>Auto</u> | <u>Q</u> | <u>Test.</u><br><u>H<sub>0</sub></u> | <u>Test</u><br><u>SHP</u> | <u>Active</u><br><u>SHP</u> |
|-----------|------------|--------------|-------------|----------|--------------------------------------|---------------------------|-----------------------------|
| 244       | 1.50       | 12.25        | 33"         | 12.02    | 3.90                                 | 7                         | 5                           |
| 245       |            |              |             | 17.05    | 8.06                                 | 22                        | 15                          |
| 246       |            |              |             | 16.27    | 7.26                                 | 19                        | 16                          |
| 247       |            |              |             | 38.06    | 27.91                                | 148                       | 120                         |
| 248       |            |              |             | 42.12    | 32.39                                | 215                       | 178                         |
| 249       |            |              |             | 29.27    | 21.90                                | 101                       | 71                          |
| 250       |            |              |             | 25.43    | 17.55                                | 70                        | 40                          |
| 251       |            |              |             | 10.77    | 3.49                                 | 6                         | 5                           |
| 252       |            |              |             | 16.07    | 7.76                                 | 20                        | 20                          |
| 253       |            |              |             | 21.00    | 13.25                                | 44                        | 46                          |
| 253       |            |              |             | 21.66    | 14.10                                | 48                        | 46                          |
| 254       |            |              |             | 24.96    | 18.72                                | 74                        | 86                          |
| 255       |            |              |             | 31.28    | 29.40                                | 145                       | 160                         |
| 256       |            |              |             | 36.79    | 41.11                                | 240                       | 222                         |

BOLINED TESTS



# CAVITATION LIMITS (BALANCE TESTS)

1.50 PPM/1225 NO. 6

$$S = \frac{21.19 N \sqrt{Q}}{(H_s - H_v)^{3/4}}$$

$$H_{I_2} = H_{D.M.} + APSI \left( \frac{144}{100} \right)^{1.25}$$

$$H_{D.M.} = 32.12' \quad (100 \text{ ft})$$

$$H_{I_2} = 32.12 + 2308 \text{ APSI} + 75 = 32.12 + 2308 \text{ APSI}$$

$$H_v = 170'$$

$$S = \frac{21.19 N \sqrt{Q}}{(32.12 + 2308 \text{ APSI} - 170)^{3/4}} = \frac{21.19 N \sqrt{Q}}{(31.12 + 2308 \text{ APSI})^{3/4}}$$

| <u>PSI</u> | <u>INCH</u> | <u>N</u> | <u>Q</u> | <u>APSI</u> | <u>S</u> | <u>T<sub>2</sub></u> | <u>K<sub>r</sub></u> |
|------------|-------------|----------|----------|-------------|----------|----------------------|----------------------|
| 212        | 23"         | 633      | 807      | 1.50        | 6930     | 168                  | .42                  |
| 213        | 0           | 919      | 1470     | 1.28        | 6000     | 4.8                  | .54                  |
| 214        |             | 1213     | 2774     | 1.17        | 5167     | 8.67                 | .59                  |
| 215        |             | 1516     | 4530     | 1.03        | 4389     | 14.20                | .62                  |
| 216        |             | 1820     | 6770     | .92         | 3622     | 21.25                | .63                  |
| 217        |             | 2123     | 9038     | .84         | 2973     | 29.54                | .63                  |
| 225        | 19.5        | 277      | 1111     | .75         | 3528     | 204                  | .52                  |
| 227        | Δ           | 70       | 151      | .65         | 6340     | 522                  | .51                  |
| 230        |             | 1211     | 2770     | .62         | 10670    | 2.2                  | .53                  |
| 231        |             | 1500     | 4071     | .57         | 13603    | 1.14                 | .57                  |
| 232        |             | 1819     | 5771     | .52         | 2571     | 2176                 | .53                  |
| 233        |             | 1819     | 5771     | .52         | 2717     | 2140                 | .57                  |
| 233        |             | 2042     | 7635     | .47         | 40821    | 2538                 | .53                  |
| 251        | 33"         | 587      | 777      | .80         | 3146     | 232                  | .50                  |
| 252        | □           | 920      | 1277     | .70         | 6205     | 522                  | .53                  |
| 253        |             | 1215     | 2070     | .62         | 10520    | 250                  | .57                  |
| 253        |             | 1215     | 2070     | .62         | 1516     | 230                  | .57                  |
| 255        |             | 1507     | 2770     | .57         | 17322    | 1.14                 | .57                  |
| 255        |             | 1827     | 4071     | .52         | 25302    | 2140                 | .57                  |
| 255        |             | 2127     | 5771     | .47         | 32231    | 2571                 | .53                  |

# Cavitation Limits (SAFETY TESTS)

1.50 Prop/1225 No.21

$$S = \frac{21.19 N \sqrt{Q}}{(H_{fs} - H_{fn})^{3/4}}$$

$$H_{fs} = H_{fn} + \text{APSI} \left( \frac{14.7}{62.4} \right) + 1.1$$

$$H_{fn} = 32.12'$$

(1.500' -)

$$H_{fs} = 32.12 + 2.476 \text{ (APSI)} + 1.1 = 32.70' + 2.308 \text{ (APSI)}$$

$$S = \frac{21.19 N \sqrt{Q}}{(32.70 + 2.308 \text{ (APSI)} - 1)^{3/4}} = \frac{21.19 N \sqrt{Q}}{(31.47 + 2.308 \text{ (APSI)})^{3/4}}$$

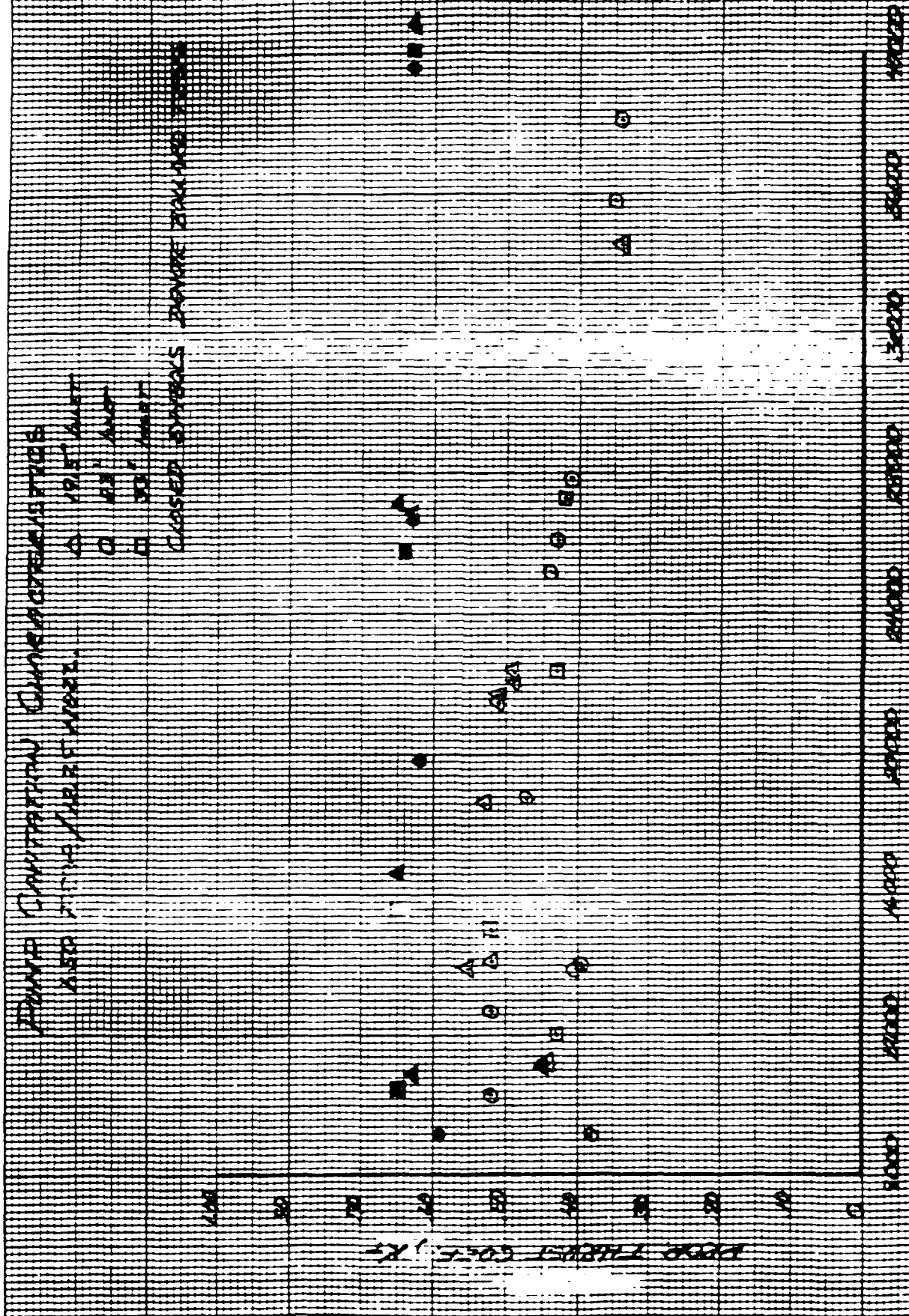
| <u>RN</u> | <u>ln</u> | <u>N</u> | <u>Q</u> | <u>APSI</u> | <u>S</u> | <u>T<sub>s</sub></u> | <u>K<sub>t</sub></u> |
|-----------|-----------|----------|----------|-------------|----------|----------------------|----------------------|
| 201       | 23        | 248      | 16.06    | +2.24       | 4842     | 296                  | .41                  |
| 202       | 2         | 1223     | 32.95    | -2.99       | 18763    | 1403                 | .47                  |
| 203       |           | 2101     | 40.35    | -4.29       | 61767    | 1811                 | .41                  |
| 204       |           | 2097     | 40.27    | -3.53       | 61113    | 1876                 | .43                  |
| 205       |           | 2381     | 42.25    | -5.52       | 25883    | 1993                 | .35                  |
| 206       |           | 1434     | 27.48    | +1.24       | 1266     | 1150                 | .52                  |
| 207       |           | 1563     | 27.37    | -1.26       | 10280    | 1202                 | .52                  |
| 208       |           | 1321     | 26.20    | -5.20       | 13711    | 980                  | .40                  |
| 209       |           | 1371     | 26.16    | -3.44       | 14070    | 950                  | .39                  |
| 210       |           | 1107     | 21.02    | -2.14       | 7114     | 768                  | .35                  |
| 211       |           | 1103     | 21.77    | -2.16       | 9091     | 450                  | .36                  |
| 218       |           | 43       | 7.25     | -1.13       | 2135     | 171                  | .58                  |
| 219       |           | 1961     | 36.94    | -4.45       | 25207    | 1536                 | .44                  |
| 220       |           | 2400     | 41.00    | -6.64       | 26111    | 74                   | .34                  |

# CAVITATION LIMITS (SPEED TESTS)

1.50 Prop / 12.25" No 22 (CONT.)

| <u>RUN</u> | <u>INLET</u> | <u>N</u> | <u>Q</u> | <u>API</u> | <u>S</u> | <u>T<sub>s</sub></u> | <u>K<sub>s</sub></u> |
|------------|--------------|----------|----------|------------|----------|----------------------|----------------------|
| 221        | 19.5         | 610      | 12.37    | - .36      | 3165     | 179                  | .54                  |
| 222        | Δ            | 832      | 15.56    | - .89      | 5937     | 493                  | .62                  |
| 223        |              | 883      | 15.52    | - .99      | 5815     | 497                  | .64                  |
| 224        |              | 1849     | 33.81    | - 3.24     | 21525    | 1728                 | .51                  |
| 225        |              | 1873     | 34.38    | - 4.02     | 22457    | 1710                 | .49                  |
| 226        |              | 1458     | 26.8     | - 2.68     | 13855    | 1175                 | .55                  |
| 227        |              | 1257     | 23.39    | - 2.21     | 11238    | 993                  | .44                  |
| 234        |              | 643      | 12.71    | - .48      | 3570     | 206                  | .50                  |
| 235        |              | 862      | 15.82    | - .89      | 5871     | 470                  | .63                  |
| 236        |              | 1875     | 34.20    | - 3.60     | 21727    | 1786                 | .51                  |
| 237        |              | 520      | 30.36    | - .54      | 4664     | 123                  | .49                  |
| 238        |              | 2412     | 36.91    | - 5.70     | 34510    | 266                  | .34                  |
| 239        |              | 1278     | 33.14    | - 3.29     | 18620    | 1489                 | .53                  |
| 240        |              | 1872     | 34.62    | - 3.08     | 22118    | 1699                 | .49                  |
| 241        |              | 1412     | 26.57    | - 3.0      | 14078    | 1247                 | .52                  |
| 242        |              | 124      | 23.74    | - 2.57     | 11186    | 924                  | .45                  |
| 243        |              | 295      | 14.77    | - 1.25     | 5221     | 311                  | .49                  |
| 244        | 33'          | 620      | 12.22    | - .12      | 3600     | 207                  | .57                  |
| 245        | II           | 832      | 12.35    | - .16      | 5202     | 447                  | .61                  |
| 246        |              | 872      | 12.27    | - .17      | 5245     | 453                  | .60                  |
| 247        |              | 1870     | 36.26    | - 3        | 22353    | 1536                 | .48                  |
| 248        |              | 2146     | 42.12    | - 3.0      | 27257    | 1937                 | .42                  |
| 249        |              | 1495     | 29.27    | - 2.64     | 14382    | 1150                 | .52                  |
| 250        |              | 1296     | 25.13    | - 2.52     | 12009    | 918                  | .50                  |

PUMP CAPACITY CHARACTERISTICS  
 AND TIME/PERCENTAGE  
 A 10% AHEAD  
 D 10% AHEAD  
 H 10% AHEAD  
 CLOSED SYSTEMS PUMP HEAD AND SPEED



# CAVITATION LIMITS (BOLLARD TESTS)

1.50 PROP.

$$\sigma_T = \frac{H_{E_2} - H_{vap}}{\frac{V_L^2}{2g}}$$

$$H_{E_2} = H_{atm} + APSI \left( \frac{144}{514} \right) + .75$$

$$H_{atm} = 32.12'$$

$$H_{E_2} = 32.12 + 2.308 APSI + .75 = 32.87 + 2.308 APSI$$

$$H_{vap} = 1.00'$$

$$\frac{V_L^2}{2g} = \left( \frac{Q}{A} \right)^2 \frac{1}{2g} + \left( \frac{\pi D N}{60} \right)^2 \frac{1}{2g} = \frac{Q^2}{(1.0434)^2 (2)(32.2)} + \left( \frac{(1.167 \pi N)}{60} \right)^2 \frac{1}{2g}$$

$$= .0143 Q^2 + .000058 N^2$$

$$\sigma_T = \frac{32.87 + 2.308 APSI - 1}{.0143 Q^2 + .000058 N^2} = \frac{31.87 + 2.308 APSI}{.0143 Q^2 + .000058 N^2}$$

$$K_T = \frac{\bar{T}_s}{\rho m^2 D^4} = \frac{\bar{T}_s}{(1.94) \left( \frac{N}{60} \right)^4 \left( \frac{1}{12} \right)^4} = 1002 \frac{\bar{T}_s}{N^4}$$

| <u>RN*</u> | <u>1/32</u> | <u>4/32</u> | <u>Q</u> | <u>APSI</u> | <u>N</u> | <u><math>\sigma_T</math></u> | <u><math>\bar{T}_s</math></u> | <u><math>K_T</math></u> |
|------------|-------------|-------------|----------|-------------|----------|------------------------------|-------------------------------|-------------------------|
| 212        | 12.25       | 23          | 907      | -1.52       | 633      | .27                          | 168                           | 42                      |
| 213        |             | 0           | 1070     | -1.28       | 719      | .36                          | 458                           | 54                      |
| 214        |             |             | 2004     | -1.17       | 1213     | .32                          | 907                           | 59                      |
| 215        |             |             | 2530     | 4.31        | 1518     | .15                          | 120                           | 62                      |
| 216        |             |             | 3000     | 6.72        | 1840     | .08                          | 225                           | 63                      |
| 217        |             |             | 3538     | 8.49        | 2057     | .05                          | 200                           | 63                      |
| 226        | 12.25       | 17.5        | 1141     | 1.26        | 630      | .20                          | 204                           | 52                      |
| 229        |             | $\Delta$    | 1375     | 1.50        | 910      | .55                          | 502                           | 61                      |
| 230        |             |             | 2000     | 2.67        | 1211     | .27                          | 77                            | 63                      |
| 231        |             |             | 2004     | 4.10        | 1500     | .15                          | 100                           | 65                      |
| 232        |             |             | 3000     | 5.25        | 1819     | .08                          | 200                           | 63                      |
| 232        |             |             | 3005     | 6.68        | 1819     | .08                          | 200                           | 65                      |
| 233        |             |             | 3035     | 3.07        | 2042     | .05                          | 200                           | 63                      |
| 251        | 12.25       | 33          | 1000     | 2           | 587      | .41                          | 232                           | 67                      |
| 252        |             | $\bar{I}$   | 1300     | 1.76        | 700      | .54                          | 232                           | 63                      |
| 253        |             |             | 2000     | 2.70        | 1215     | .27                          | 250                           | 65                      |
| 253        |             |             | 2000     | 2.70        | 1215     | .28                          | 200                           | 65                      |
| 254        |             |             | 2490     | 4.2         | 1507     | .16                          | 400                           | 65                      |
| 255        |             |             | 3000     | 5.25        | 1827     | .08                          | 200                           | 64                      |
| 256        |             |             | 3679     | 8.40        | 2055     | .05                          | 200                           | 63                      |

# CAVITATION LIMITS (SPEED TESTS)

150 PROP

$$\sigma_f = \frac{H_{fs} - H_{vap}}{\frac{V_f}{2g}}$$

$$H_{fs} = H_{atm} + APSI \left( \frac{V_f}{2g} \right) + .25'$$

$$H_{atm} = 32.12'$$

$$H_{fs} = 32.12 + 2.308 APSI + .25' = 32.37 + 2.308 APSI$$

$$H_{vap} = 100'$$

$$\frac{V_f^2}{2g} = \left( \frac{Q}{A} \right)^2 \frac{1}{2g} + \left( \frac{7.2DN}{60} \right)^2 \frac{1}{2g} = \frac{Q^2}{(1.0434)^2 (2)(32.2)} + \left( \frac{1.167 \pi N}{60} \right)^2 \frac{1}{2(32.2)}$$

$$= .0143 Q^2 + .000058 N^2$$

$$\sigma_f = \frac{32.37 + 2.308 APSI - 1}{.0143 Q^2 + .000058 N^2} = \frac{31.37 + 2.308 APSI}{.0143 Q^2 + .000058 N^2}$$

$$K_f = \frac{T_b}{\rho n^2 D^5} = \frac{T_b}{(1.94) \left( \frac{N}{60} \right)^2 \left( \frac{ft}{12} \right)^5} = 1002 \frac{T_b}{N^2}$$

| $Re_N^*$ | $N_{br}$ | $W_{br}$ | $Q$   | $APSI$ | $N$  | $\sigma_f$ | $T_b$ | $K_f$ |
|----------|----------|----------|-------|--------|------|------------|-------|-------|
| 801      | 12.25    | 23       | 16.06 | -2.04  | 248  | .51        | 276   | .41   |
| 721      |          | 0        | 32.35 | -2.79  | 1723 | .13        | 253   | .47   |
| 703      |          |          | 47.35 | -4.29  | 2101 | .08        | 241   | .41   |
| 204      |          |          | 50.27 | -3.13  | 2072 | .09        | 236   | .43   |
| 205      |          |          | 42.55 | -5.52  | 2324 | .05        | 226   | .55   |
| 206      |          |          | 27.45 | -1.21  | 1457 | .25        | 215   | .72   |
| 207      |          |          | 29.60 | -1.26  | 1500 | .30        | 222   | .72   |
| 208      |          |          | 26.10 | -1.30  | 1394 | .20        | 240   | .70   |
| 209      |          |          | 26.50 | -1.34  | 1394 | .19        | 240   | .70   |
| 210      |          |          | 21.02 | -2.11  | 1109 | .35        | 216   | .75   |
| 211      |          |          | 22.79 | -2.20  | 1106 | .35        | 210   | .75   |
| 218      |          |          | 22.5  | -2.25  | 495  | 2.00       | 211   | .75   |
| 219      |          |          | 30.74 | -1.45  | 1761 | .09        | 216   | .77   |
| 220      |          |          | 41.00 | -1.24  | 2400 | .05        | 211   | .77   |

# CAVITATION LIMITS (SPEED TESTS)

## 1.50 PROP. (CONT.)

| <u>R<sub>W</sub></u> | <u>1622</u> | <u>1622</u> | <u>Q</u> | <u>AP<sub>1</sub></u> | <u>N</u> | <u>ST</u> | <u>T<sub>0</sub></u> | <u>K<sub>1</sub></u> |
|----------------------|-------------|-------------|----------|-----------------------|----------|-----------|----------------------|----------------------|
| 221                  | 12.25       | 19.5"       | 10.37    | -.36                  | 610      | .34       | 199                  | .54                  |
| 222                  |             | Δ           | 16.06    | -.89                  | 892      | .60       | 493                  | .62                  |
| 223                  |             |             | 15.54    | -.99                  | 883      | .61       | 490                  | .64                  |
| 224                  |             |             | 33.61    | -3.24                 | 1849     | .11       | 1725                 | .51                  |
| 225                  |             |             | 34.38    | -4.02                 | 1873     | .10       | 1710                 | .49                  |
| 226                  |             |             | 26.18    | -2.68                 | 1458     | .19       | 1135                 | .55                  |
| 227                  |             |             | 23.39    | -2.61                 | 1257     | .26       | 603                  | .44                  |
| 234                  |             |             | 11.71    | -.48                  | 643      | 1.19      | 206                  | .50                  |
| 235                  |             |             | 16.82    | -.89                  | 962      | .68       | 470                  | .63                  |
| 236                  |             |             | 34.20    | -3.60                 | 1875     | .11       | 1786                 | .51                  |
| 237                  |             |             | 30.36    | -.54                  | 520      | 1.06      | 133                  | .49                  |
| 238                  |             |             | 36.91    | -5.20                 | 2412     | .05       | 966                  | .34                  |
| 239                  |             |             | 33.14    | -3.09                 | 1678     | .14       | 1489                 | .53                  |
| 240                  |             |             | 34.62    | -3.25                 | 1872     | .10       | 1727                 | .49                  |
| 241                  |             |             | 26.67    | -3.10                 | 1426     | .19       | 1047                 | .52                  |
| 242                  |             |             | 23.94    | -2.51                 | 1245     | .27       | 77                   | .45                  |
| 243                  |             |             | 14.99    | -1.25                 | 595      | .73       | 211                  | .49                  |
| 244                  | 12.25       | 33"         | 12.02    | -.61                  | 637      | 1.19      | 205                  | .51                  |
| 245                  |             | □           | 17.05    | -1.16                 | 860      | .62       | 445                  | .61                  |
| 246                  |             |             | 16.27    | -1.19                 | 872      | .61       | 443                  | .60                  |
| 247                  |             |             | 38.26    | -3.11                 | 1874     | .11       | 1726                 | .43                  |
| 248                  |             |             | 42.12    | -3.43                 | 2440     | .08       | 1727                 | .42                  |
| 249                  |             |             | 29.27    | -2.28                 | 1425     | .18       | 1150                 | .52                  |
| 250                  |             |             | 25.43    | -2.52                 | 1276     | .24       | 77                   | .43                  |

# PUMP CAVITATION CHARACTERISTICS 150 PSI PRESSURE

A 150 PSI  
 B 150 PSI  
 C 150 PSI  
 D 150 PSI  
 E 150 PSI  
 F 150 PSI  
 G 150 PSI  
 H 150 PSI  
 I 150 PSI  
 J 150 PSI  
 K 150 PSI  
 L 150 PSI  
 M 150 PSI  
 N 150 PSI  
 O 150 PSI  
 P 150 PSI  
 Q 150 PSI  
 R 150 PSI  
 S 150 PSI  
 T 150 PSI  
 U 150 PSI  
 V 150 PSI  
 W 150 PSI  
 X 150 PSI  
 Y 150 PSI  
 Z 150 PSI

CAVITATION NO., OF (NOT READ TIP)

TITANITE SOLIDUS POINTS

PROB. THRUST COEF.,  $K_T$

CAVITATION NO., OF (NOT READ TIP)

# CANTATION LIMITS (Boussinesq Tests)

## PROP. COMPARISON

$$\sigma = \frac{H_{E_0} - H_{E_{AP}}}{V_E^2 / z_0}$$

$$H_{E_0} = H_{E_{AP}} + APSI \left( \frac{IN}{62.4} \right) + .75$$

$$H_{E_{AP}} = 32.12'$$

$$H_{E_0} = 32.12 + 2.308 APSI + .75 = 32.87 + 2.308 APSI$$

$$H_{E_{AP}} = 1.00'$$

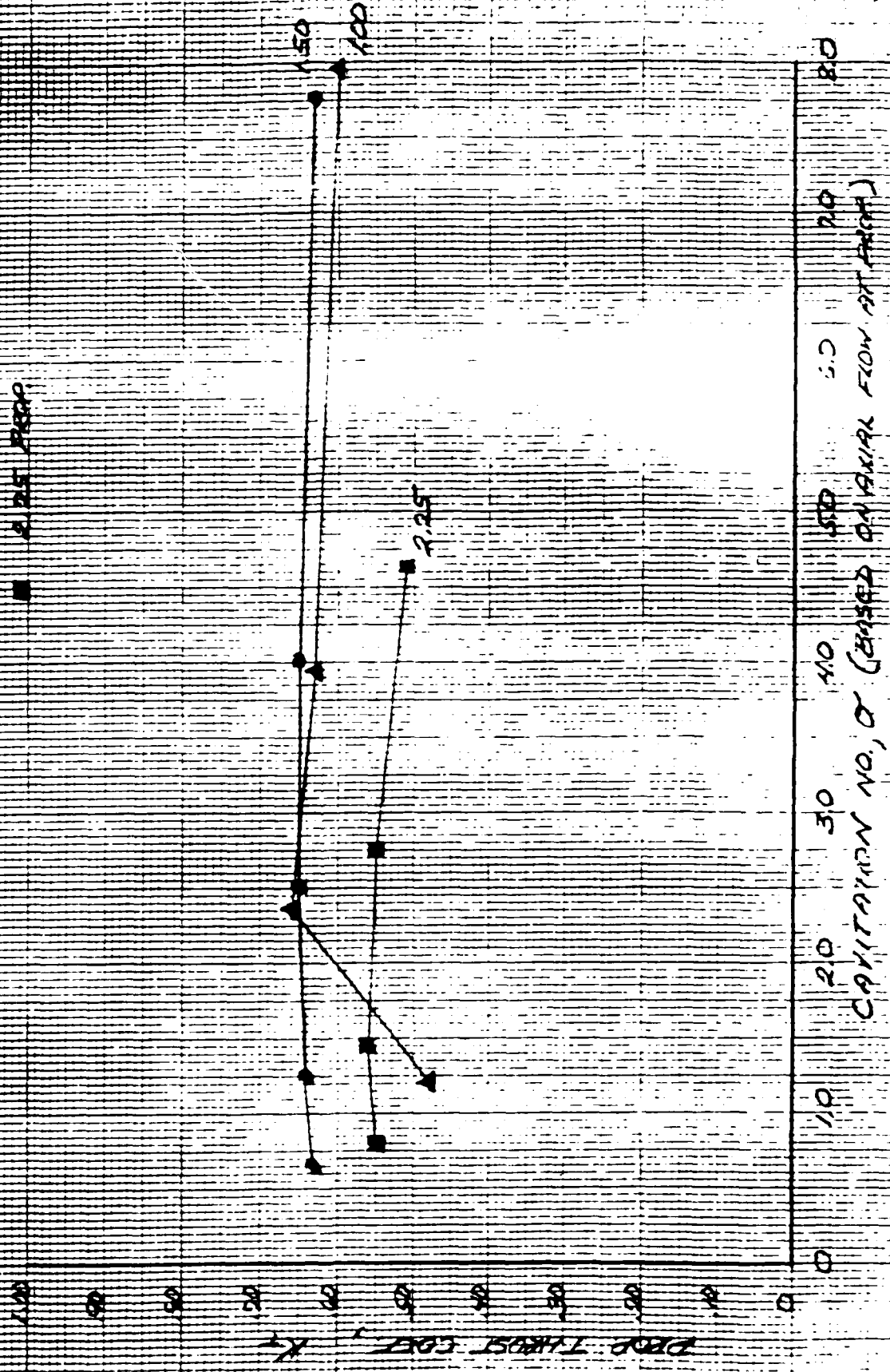
$$\frac{V_E^2}{z_0} = \left( \frac{Q}{2} \right)^2 \frac{1}{z_0} = \frac{Q^2}{(1.0434)^2 (2)(37.1)} = .0143 Q^2$$

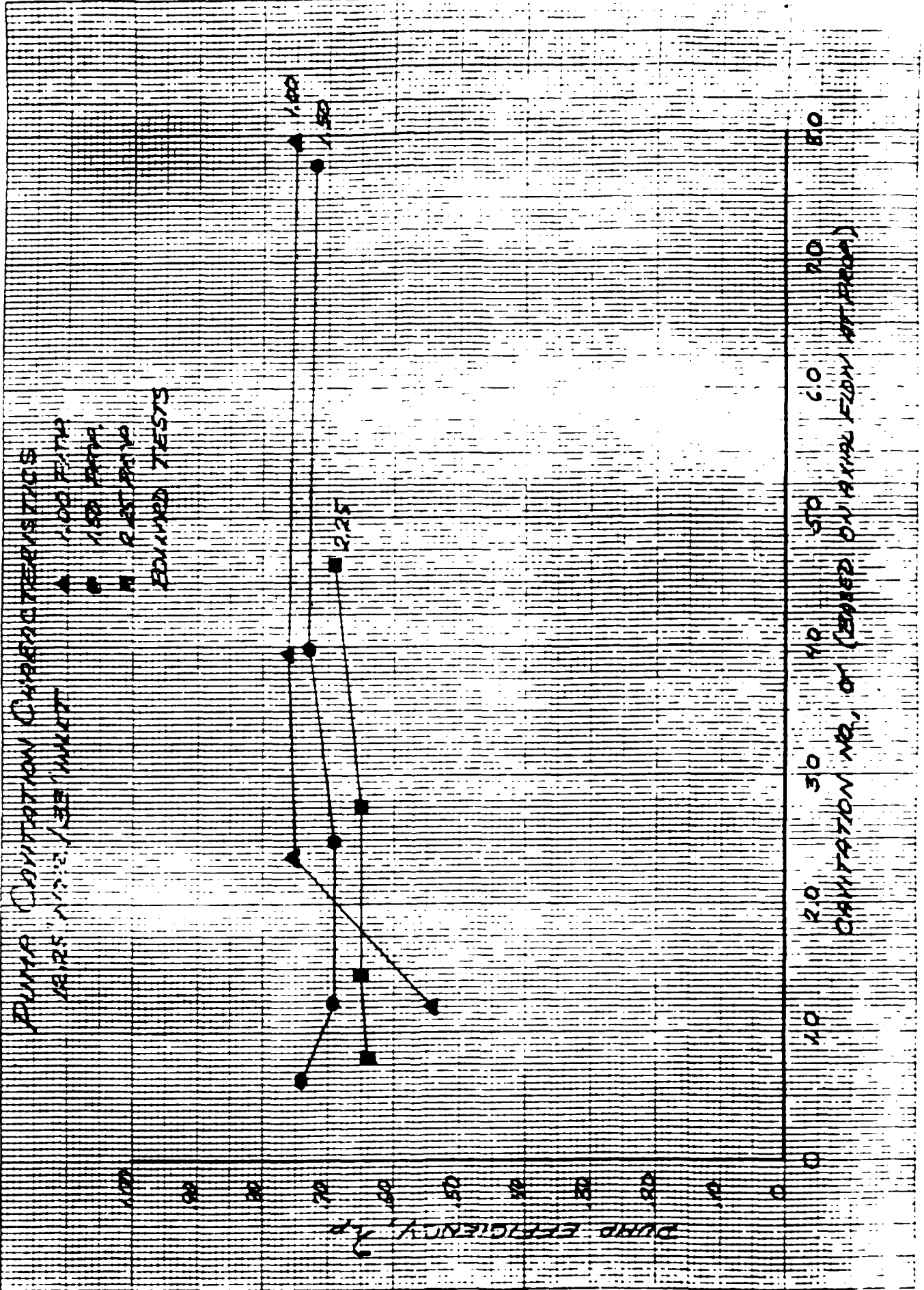
$$\sigma = \frac{32.87 + 2.308 APSI - 1}{.0143 Q^2} = \frac{31.87 + 2.308 APSI}{.0143 Q^2}$$

$$K_r = \frac{T_s}{\rho m^2 D^4} = \frac{T_s}{(19.4 \frac{N}{m^2}) \left( \frac{1}{100} \right)^4} = 1002 \frac{T_s}{N^2}$$

| <u>RUN</u> | <u>PSI</u> | <u>IN</u> | <u>INCH</u> | <u>Q</u> | <u>APSI</u> | <u>T</u> | <u>T<sub>s</sub></u> | <u>N</u> | <u>K<sub>r</sub></u> | <u>Z<sub>p</sub></u> | <u>U</u> |
|------------|------------|-----------|-------------|----------|-------------|----------|----------------------|----------|----------------------|----------------------|----------|
| 251        | 1.50       | 12.25     | 33'         | 10.77    | -1.60       | 15.38    | 232                  | 587      | .67                  | .81                  | .86      |
| 252        | 0          |           |             | 16.27    | -1.38       | 2.77     | 542                  | 720      | .3                   | .52                  | .71      |
| 253        |            |           |             | 21.00    | -2.74       | 3.78     | 756                  | 1215     | .67                  | .73                  | .8       |
| 254        |            |           |             | 24.96    | -4.12       | 2.49     | 465                  | 100      | .57                  | .57                  | .76      |
| 255        |            |           |             | 31.28    | -6.37       | 1.23     | 226                  | 1827     | .67                  | .53                  | .82      |
| 256        |            |           |             | 36.79    | -8.72       | 1.07     | 2371                 | 2055     | .63                  | .54                  | .87      |
| 310        | 2.25       | 12.25     | 33"         | 10.25    | -1.26       | 17.1     | 55                   | 601      | .15                  | .63                  | .82      |
| 311        | □          |           |             | 13.60    | -1.89       | 12.75    | 315                  | 824      | .41                  | .5                   | .76      |
| 312        |            |           |             | 20.24    | -2.03       | 4.54     | 256                  | 1214     | .57                  | .57                  | .78      |
| 313        |            |           |             | 24.31    | -3.69       | 2.76     | 127                  | 1137     | .55                  | .57                  | .76      |
| 314        |            |           |             | 29.17    | -5.89       | 1.46     | 1267                 | 1818     | .55                  | .57                  | .76      |
| 315        |            |           |             | 34.20    | -8.08       | .79      | 2220                 | 2065     | .55                  | .57                  | .76      |
| 100        |            | 12.25     | 33"         | 10.31    | -1.65       | 19.98    | 220                  | 620      | .57                  | .67                  | .78      |
| Δ          |            |           |             | 15.71    | -1.63       | 7.96     | 500                  | 910      | .60                  | .75                  | .81      |
|            |            |           |             | 20.98    | -3.05       | 3.74     | 700                  | 1200     | .63                  | .76                  | .84      |
|            |            |           |             | 25.25    | -4.50       | 2.36     | 1312                 | 1410     | .60                  | .75                  | .81      |
|            |            |           |             | 30.61    | -6.70       | 1.19     | 1670                 | 1765     | .48                  | .54                  | .72      |

PUMP CAVITATION CHARACTERISTICS  
 18.25" NOZZLE / 33" INLET  
 ▲ 100 PSIA  
 ● 150 PSIA  
 ■ 2.25 PSIA

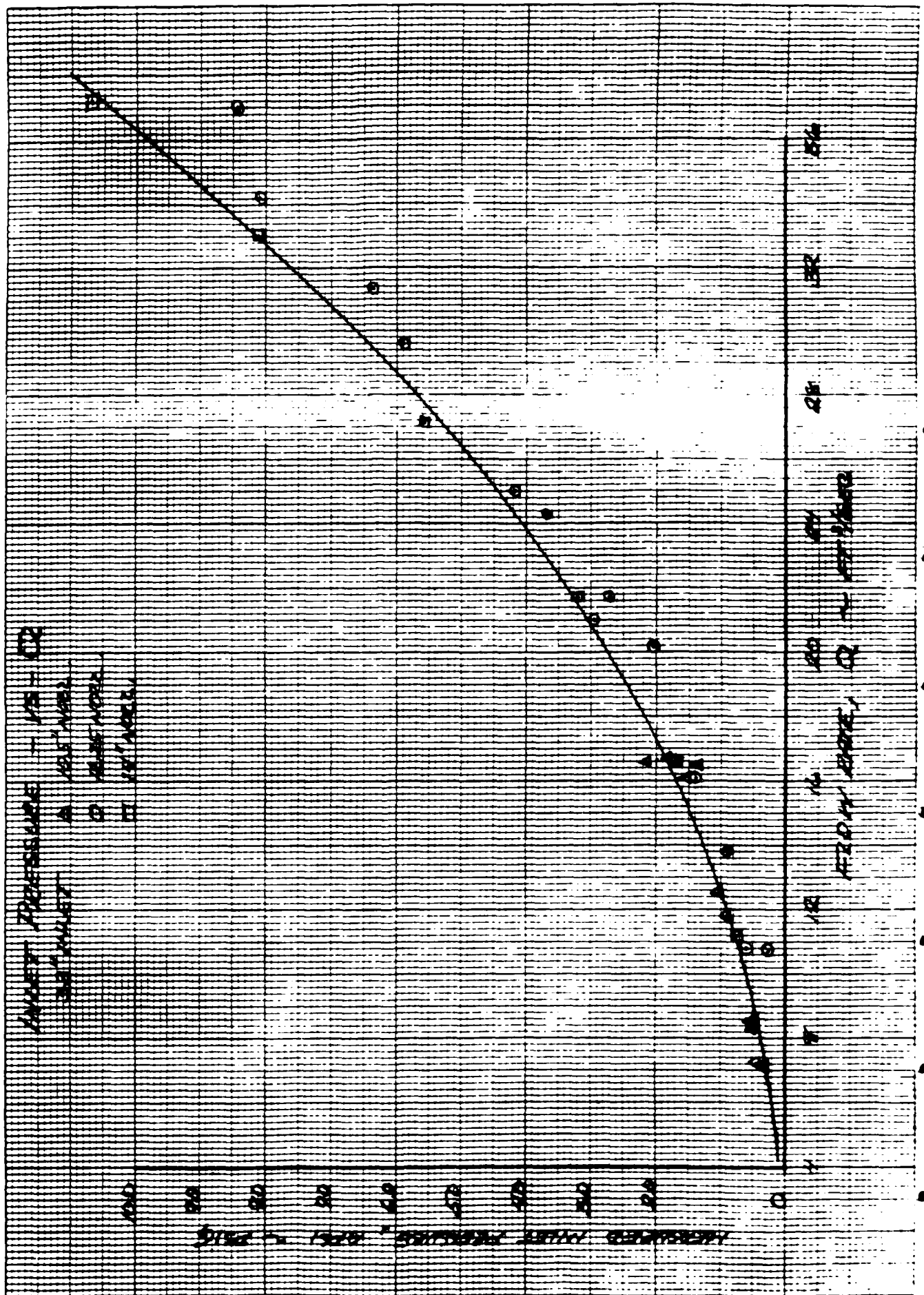




# INLET PRESSURE

## 33" INLET (BOMAR TESTS)

|        | <u>Rn</u> | <u>Nbr</u> | <u>Q</u> | <u>HP</u> |
|--------|-----------|------------|----------|-----------|
| 1.5AR  | 251       | 12.2       | 5.77     | .30       |
|        | 252       | 5          | 16.27    | 1.35      |
|        | 253       |            | 51.00    | 2.70      |
|        | 253       |            | 61.00    | 2.00      |
|        | 254       |            | 24.90    | 4.19      |
|        | 255       |            | 31.28    | 6.30      |
|        | 256       |            | 36.77    | 8.42      |
| 2.25AR | 293       | 10.5       | 7.7      | .46       |
|        | 294       | 5          | 8.25     | .57       |
|        | 295       |            | 12.57    | 1.00      |
|        | 296       |            | 16.13    | 1.54      |
|        | 297       |            | 16.57    | 2.17      |
| 2.25AR | 310       | 11.1       | 10.65    | .20       |
|        | 311       | 5          | 13.80    | .69       |
|        | 312       |            | 20.24    | 2.73      |
|        | 313       |            | 24.31    | 3.12      |
|        | 314       |            | 29.71    | 5.89      |
|        | 315       |            | 34.10    | 6.78      |
| 2.25AR | 332       | 14.70      | 11.23    | .74       |
|        | 333       | 5          | 16.22    | 1.00      |
|        | 334       |            | 21.70    | 3.24      |
|        | 335       |            | 27.10    | 5.77      |
|        | 336       |            | 32.95    | 8.39      |
|        | 337       |            | 37.10    | 10.71     |
| 1.00AR | 377       | 10.25      | 9.06     | .31       |
|        | 378       | 5          | 8.47     | .24       |
|        | 379       |            | 11.25    | .30       |
|        | 380       |            | 16.54    | .54       |
|        | 381       |            | 16.71    | 1.82      |



# CAVITATION LIMITS (BOUNDED TESTS)

1.50 Prop

$$\sigma = \frac{H_{E_2} - H_{vap}}{\frac{V_E}{2g}}$$

$$H_{E_2} = H_{a.m} + APSI \left( \frac{144}{62.4} \right) + .75'$$

$$H_{a.m} = 32.12'$$

$$H_{E_2} = 32.12 + 2.308 APSI + .75' = 32.87 + 2.308 APSI$$

$$H_{vap} = 1.00'$$

$$\frac{V_E^2}{2g} = \left( \frac{Q}{A} \right)^2 \frac{1}{2g} = \frac{Q^2}{(1.0434)^2 (2)(32.2)} = .0143 Q^2$$

$$\sigma = \frac{32.87 + 2.308 APSI - 1}{.0143 Q^2} = \frac{31.87 + 2.308 APSI}{.0143 Q^2}$$

$$K_T = \frac{T_s}{\rho N^2 D^4} = \frac{T_s}{1.94 \left( \frac{N}{60} \right)^4 \left( \frac{14}{12} \right)^4} = 1002 \frac{T_s}{N^2}$$

| <u>Run#</u> | <u>N<sub>rev</sub></u> | <u>1/rev</u> | <u>Q</u> | <u>APSI</u> | <u>σ</u> | <u>T<sub>s</sub></u> | <u>N</u> | <u>K<sub>T</sub></u> | <u>J</u> | <u>z<sub>o</sub></u> |
|-------------|------------------------|--------------|----------|-------------|----------|----------------------|----------|----------------------|----------|----------------------|
| 212         | 12.25                  | 23           | 9.07     | -1.50       | 32.83    | 106                  | 623      | .42                  | .60      | .73                  |
| 213         | "                      | "            | 14.26    | -1.28       | 9.28     | 458                  | 7.7      | .54                  | .55      | .72                  |
| 214         | "                      | "            | 20.04    | -1.17       | 5.75     | 367                  | 2.3      | .59                  | .57      | .73                  |
| 215         | "                      | "            | 25.30    | -1.31       | 8.40     | -22                  | 15.8     | .62                  | .58      | .71                  |
| 216         | "                      | "            | 31.10    | -1.22       | 1.13     | 2.25                 | 8.40     | .63                  | .59      | .71                  |
| 217         | 12.25                  | 1.1          | 35.38    | -1.44       | .57      | 2.53                 | 20.2     | .63                  | .51      | .73                  |
| 218         | "                      | "            | 11.41    | -1.86       | 16.05    | 5.21                 | 6.30     | .52                  | .65      | .62                  |
| 219         | "                      | "            | 16.25    | -1.50       | 7.42     | 5.2                  | 2.0      | .61                  | .64      | .70                  |
| 220         | "                      | "            | 22.26    | -1.27       | 3.4      | 2.7                  | 2.1      | .63                  | .66      | .75                  |
| 231         | "                      | "            | 26.04    | -1.36       | 2.15     | 1.34                 | 5.00     | .65                  | .61      | .71                  |
| 232         | "                      | "            | 31.17    | -1.51       | 1.14     | 2.22                 | 6.7      | .63                  | .62      | .69                  |
| 232         | "                      | "            | 31.65    | -1.66       | 1.12     | 2.47                 | 18.7     | .65                  | .62      | .70                  |
| 233         | "                      | "            | 36.31    | -1.57       | .83      | 2.38                 | 20.72    | .63                  | .63      | .73                  |
| 237         | 12.25                  | 33'          | 10.77    | .0          | 8.38     | 232                  | 5.87     | .67                  | .60      | .61                  |
| 237         | "                      | "            | 16.07    | 1.36        | 7.77     | 5.2                  | 7.0      | .63                  | .62      | .72                  |
| 238         | "                      | "            | 21.00    | 2.74        | 3.78     | 256                  | 12.15    | .65                  | .61      | .73                  |
| 238         | "                      | "            | 21.00    | 2.00        | 3.82     | 760                  | 12.15    | .65                  | .64      | .75                  |
| 239         | "                      | "            | 24.96    | 4.7         | 2.07     | 1.55                 | 15.07    | .65                  | .65      | .69                  |
| 239         | "                      | "            | 31.18    | 1.37        | 1.23     | 2.26                 | 19.27    | .64                  | .67      | .69                  |
| 250         | "                      | "            | 36.79    | 2.42        | .64      | 5.77                 | 20.55    | .63                  | .67      | .74                  |

# CAVITATION LIMITS (SPEED TESTS)

1.50 Prop.

$$\sigma = \frac{H_{E_s} - H_{imp}}{V_t^2 / 2g}$$

$$H_{E_s} = L/4 + APS \left( \frac{144}{32.2} \right) + .75'$$

$$H_{atm} = 32.12'$$

$$H_{E_s} = 32.12 + 2.308 APS + .75 = 32.87 + 2.308 APS$$

$$H_{imp} = 1.00'$$

$$\frac{V_t^2}{2g} = \left( \frac{Q}{A} \right)^2 \frac{L}{2g} = \frac{Q^2}{(1.0434)^2 (2)(32.2)} = .0143 Q^2$$

$$\sigma = \frac{32.87 + 2.308 APS - 1}{.0143 Q^2} = \frac{31.87 + 2.308 APS}{.0143 Q^2}$$

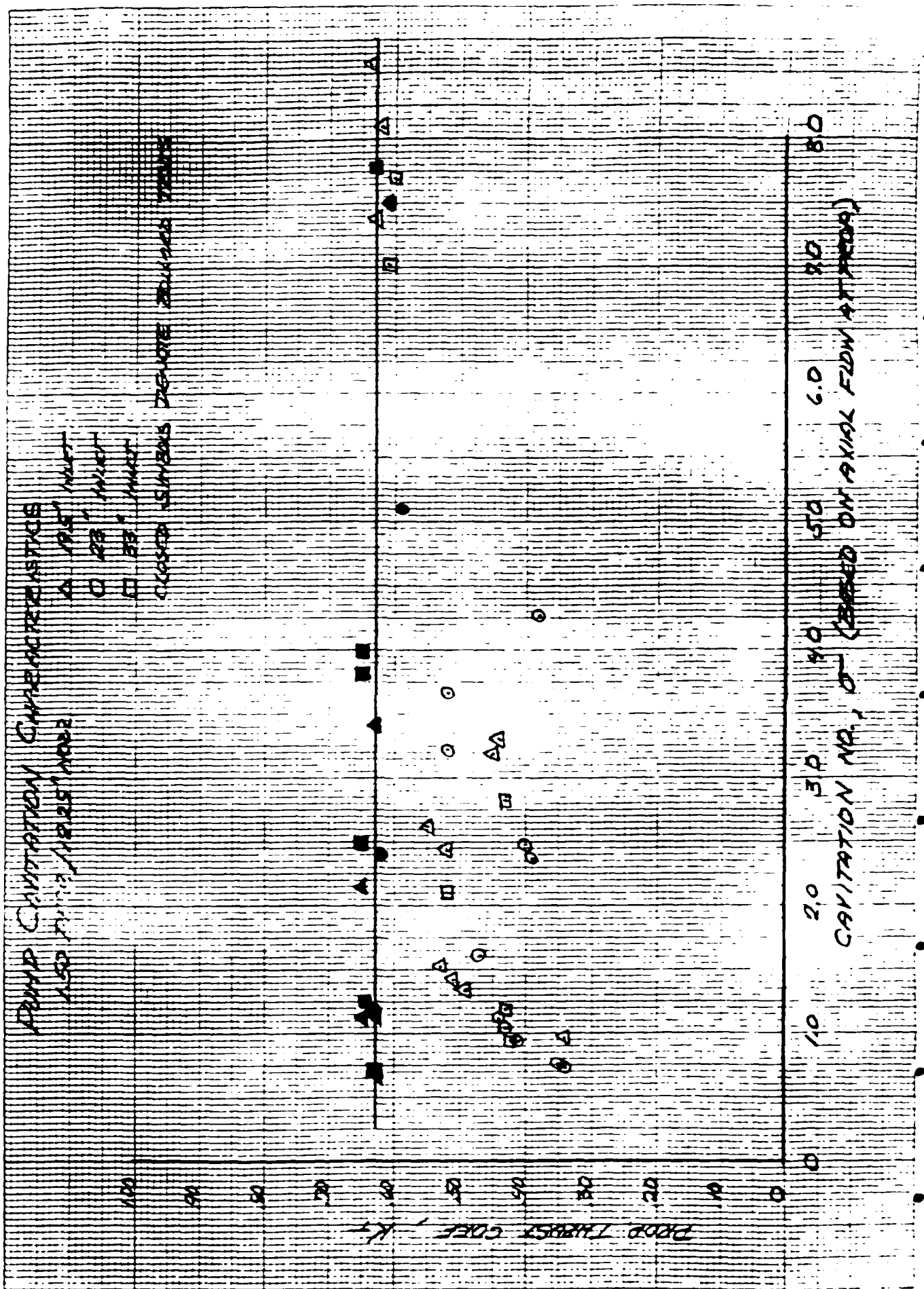
$$K_T = \frac{T_s}{\rho n^2 D^4} = \frac{T_s}{(1.94)(\frac{N}{32})^2 (\frac{14}{12})^4} = 1002 \frac{T_s}{N^2}$$

| $R_n$ | $N_b$ | $H_{imp}$ | $Q$   | $L/4$ | $\sigma$ | $T_s$ | $n$  | $K_T$ | $u$ | $z_n$ |
|-------|-------|-----------|-------|-------|----------|-------|------|-------|-----|-------|
| 201   | 12.25 | 23'       | 16.00 | +2.31 | 792      | 8.9   | 848  | .41   | .67 | .63   |
| 202   |       | 9         | 32.95 | -2.99 | 1.61     | 1403  | 1723 | .47   | .90 | .55   |
| 203   |       |           | 40.35 | -4.29 | .94      | 1511  | 2101 | .41   | .90 | .54   |
| 204   |       |           | 40.27 | -3.33 | 1.03     | 1870  | 2092 | .43   | .90 | .57   |
| 205   |       |           | 42.05 | -5.52 | .76      | 190   | 2214 | .35   | .83 | .51   |
| 206   |       |           | 27.48 | +1.24 | 322      | 1.53  | 1414 | .52   | .87 | .51   |
| 207   |       |           | 29.40 | +6.06 | 3.00     | 272   | 1.50 | .72   | .89 | .57   |
| 208   |       |           | 26.10 | -3.30 | 2.15     | 260   | 1.1  | .40   | .88 | .56   |
| 209   |       |           | 26.50 | -3.44 | 2.27     | 220   | 1.34 | .57   | .89 | .55   |
| 210   |       |           | 21.02 | -2.14 | 426      | 1.31  | 1109 | .58   | .87 | .54   |
| 211   |       |           | 20.77 | -2.16 | 427      | 4.00  | 1106 | .56   | .87 | .53   |
| 218   |       |           | 7.25  | -1.43 | 272      | 1     | 425  | .78   | .88 | .53   |
| 219   |       |           | 3.30  | -1.45 | 1.11     | 330   | 1.01 | .44   | .88 | .54   |
| 220   |       |           | 4.00  | -6.24 | .73      | 9.41  | 2.70 | .74   | .80 | .50   |

# CAVITATION LIMITS (SPEED TESTS)

## 1.5D Prop (CONT.)

| <u>RPM</u> | <u>N<sub>22</sub></u> | <u>WATER</u> | <u>Q</u> | <u>ASL</u> | <u>T</u> | <u>T<sub>s</sub></u> | <u>N</u> | <u>K<sub>T</sub></u> | <u>J</u> | <u>Z<sub>0</sub></u> |
|------------|-----------------------|--------------|----------|------------|----------|----------------------|----------|----------------------|----------|----------------------|
| 221        | 12.25"                | 19.5"        | 10.37    | -.36       | 20.18    |                      | 210      | .54                  | .80      | .26                  |
| 222        |                       | Δ            | 16.06    | -.69       | 8.58     |                      | 892      | .62                  | .64      | .63                  |
| 223        |                       |              | 15.54    | -.99       | 8.57     |                      | 883      | .54                  | .63      | .59                  |
| 224        |                       |              | 33.81    | -3.24      | 1.42     |                      | 1849     | .51                  | .46      | .24                  |
| 225        |                       |              | 34.38    | -4.02      | 1.34     |                      | 1873     | .49                  | .66      | .25                  |
| 226        |                       |              | 26.18    | -2.68      | 2.62     |                      | 1458     | .55                  | .64      | .23                  |
| 227        |                       |              | 23.89    | 2.61       | 3.30     |                      | 1257     | .44                  | .87      | .21                  |
| 231        |                       |              | 11.21    | .48        | 15.69    |                      | 643      | .50                  | .65      | .22                  |
| 235        |                       |              | 16.82    | .89        | 2.37     |                      | 862      | .3                   | .92      | .64                  |
| 236        |                       |              | 21.15    | 3.60       | 1.41     |                      | 1875     | .51                  | .86      | .24                  |
| 237        |                       |              | 30.36    | .74        | 2.32     |                      | 520      | .49                  | 2.74     | 2.64                 |
| 238        |                       |              | 36.31    | 5.20       | .76      |                      | 2412     | .34                  | .22      | .63                  |
| 239        |                       |              | 33.14    | 3.09       | 1.52     |                      | 1678     | .53                  | .94      | .80                  |
| 240        |                       |              | 34.62    | 3.28       | 1.35     |                      | 1872     | .49                  | .87      | .24                  |
| 241        |                       |              | 51.27    | 3.10       | 2.43     |                      | 1476     | .52                  | .88      | .23                  |
| 242        |                       |              | 63.74    | 4.51       | 3.18     |                      | 1245     | .46                  | .70      | .25                  |
| 243        |                       |              | 7.99     | 1.25       | 9.02     |                      | 595      | .49                  | .18      | .22                  |
| 244        | 12.25                 | 33"          | 12.02    | .61        | 14.74    |                      | 627      | .51                  | .63      | .28                  |
| 245        |                       |              | 17.05    | 1.16       | 2.02     |                      | 820      | .61                  | .23      | .24                  |
| 246        |                       |              | 16.27    | 1.19       | 2.67     |                      | 872      | .6                   | .25      | .24                  |
| 247        |                       |              | 31.26    | 3.11       | 1.19     |                      | 1721     | .43                  | .24      | .61                  |
| 248        |                       |              | 12.12    | 3.43       | .74      |                      | 2146     | .42                  | .22      | .25                  |
| 249        |                       |              | 29.27    | 2.24       | 2.10     |                      | 1625     | .52                  | .92      | .24                  |
| 250        |                       |              | 25.43    | 2.52       | 2.82     |                      | 1826     | .45                  | .92      | .22                  |



# PUMP CAVITATION CHARACTERISTICS

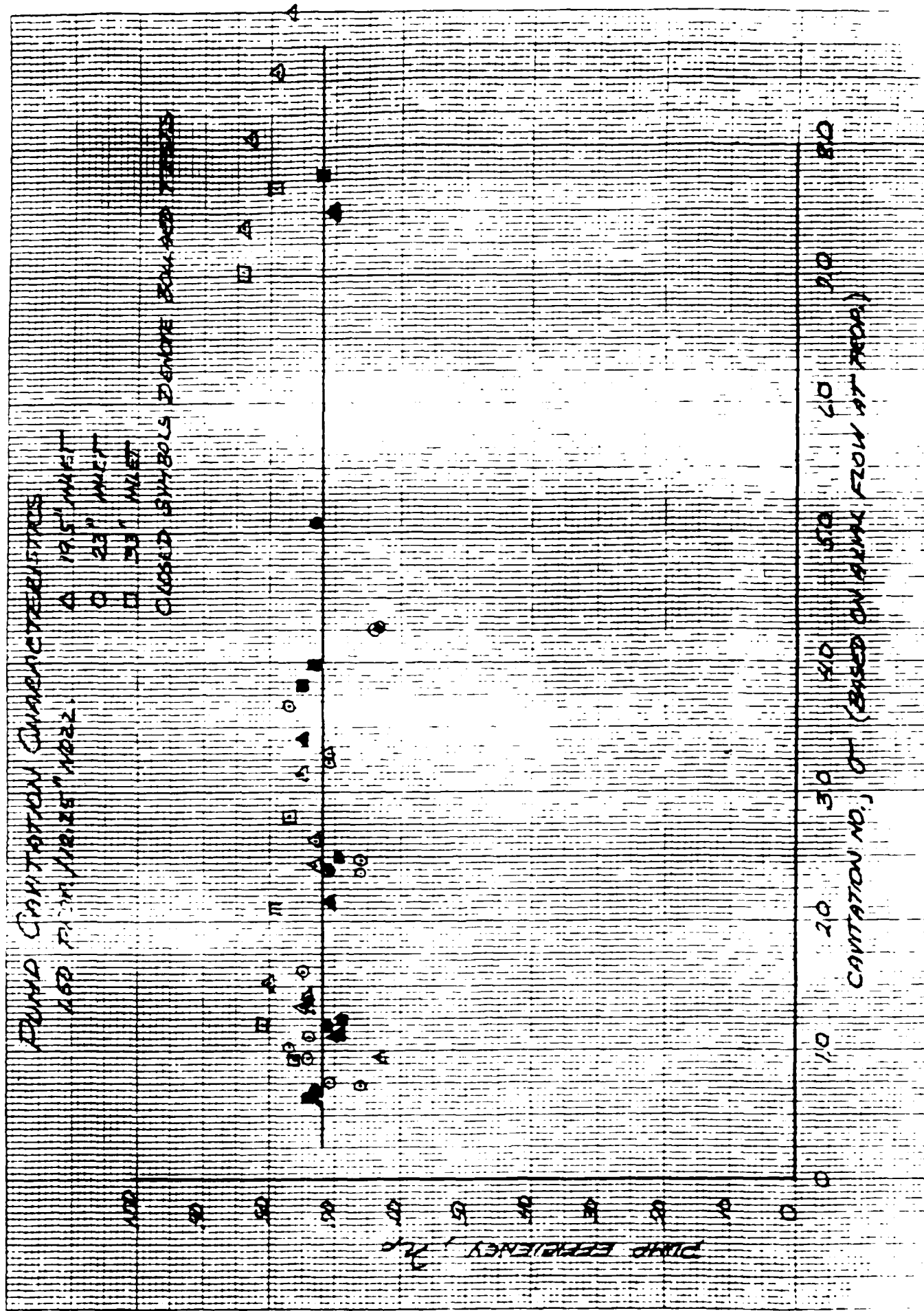
160 PSI INLET PRESSURE

19.5" WHEEL

23" WHEEL

25" WHEEL

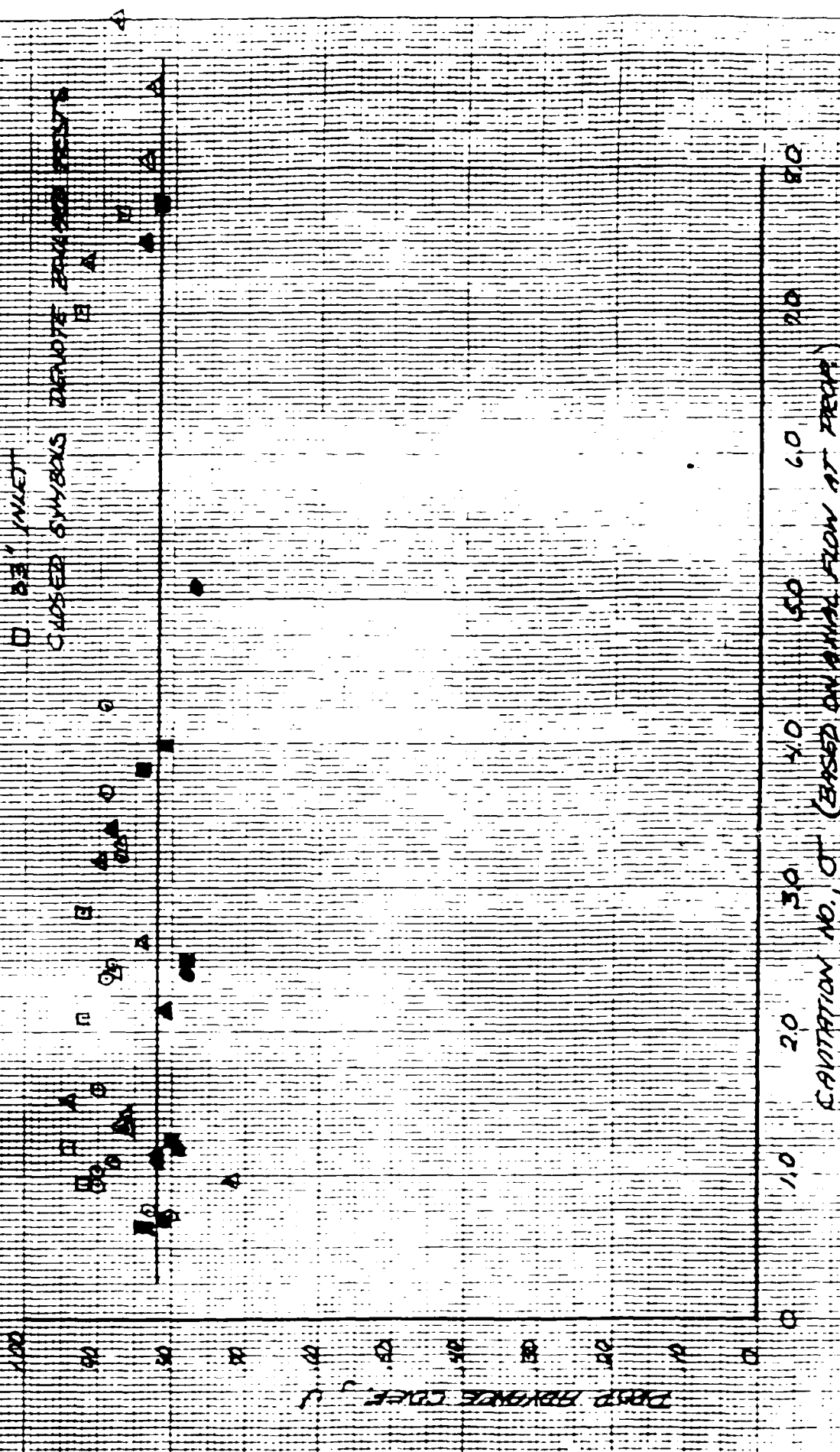
CLOSED SYMBOLS DENOTE LOW FLOW TESTS



# DUMP CAVITATION CHARACTERISTICS 180 21 20 / 1825 WGEZ.

Δ 18.5" INLET  
 ○ 23" INLET  
 □ 33" INLET

CLOSSED SYMBOLS DENOTE EXHAUST PRESS.



# VENTILATION (Speed Tests)

1.50 Prop

$$F_v = \frac{V_0}{\sqrt{g D^3}}$$

$$\nabla^{1/3} = \left( \frac{4.502}{62.4} \right)^{1/3} = 4.53$$

$$F_v = \frac{V_0}{\sqrt{(32)(4.53)}} = .0828 V_0 = .1217 V_{rpm}$$

$$K_T = \frac{T_s}{\rho n^2 D^4} = \frac{T_s}{(1.94) \left( \frac{N}{60} \right)^2 \left( \frac{1}{12} \right)^4} = 1002 \frac{T_s}{N^2}$$

$$K_{T_{ball}} = .63$$

| <u>Pw<sup>2</sup></u> | <u>No<sup>12</sup></u> | <u>1/1000</u> | <u>V<sub>0</sub></u> | <u>F<sub>v</sub></u> | <u>T<sub>s</sub></u> | <u>N</u> | <u>K<sub>T</sub></u> | <u><math>\frac{K_T}{K_{T_{ball}}}</math></u> |
|-----------------------|------------------------|---------------|----------------------|----------------------|----------------------|----------|----------------------|----------------------------------------------|
| 201                   | 12.25                  | 23            | 4.95                 | .60                  | 2.93                 | 848      | .41                  | .65                                          |
| 202                   |                        |               | 17.40                | 2.14                 | 4.03                 | 1723     | .47                  | .75                                          |
| 203                   |                        |               | 25.13                | 3.06                 | 5.11                 | 2101     | .41                  | .65                                          |
| 204                   |                        |               | 25.36                | 3.09                 | 4.86                 | 2092     | .43                  | .68                                          |
| 205                   |                        |               | 26.23                | 3.17                 | 4.96                 | 2164     | .37                  | .58                                          |
| 206                   |                        |               | 10.26                | 2.1                  | 4.5                  | 1724     | .52                  | .83                                          |
| 207                   |                        |               | 10.93                | 2.3                  | 4.72                 | 1726     | .52                  | .83                                          |
| 208                   |                        |               | 8.49                 | 1.53                 | 3.80                 | 1341     | .40                  | .63                                          |
| 209                   |                        |               | 9.40                 | 1.52                 | 3.20                 | 1341     | .39                  | .62                                          |
| 210                   |                        |               | 7.00                 | 1.5                  | 4.15                 | 1341     | .41                  | .65                                          |
| 211                   |                        |               | 7.53                 | 1.55                 | 4.27                 | 1341     | .48                  | .76                                          |
| 218                   |                        |               | 2.69                 | .33                  | 1.1                  | 1205     | .55                  | .87                                          |
| 219                   |                        |               | 22.31                | 2.12                 | 16.6                 | 1721     | .44                  | .70                                          |
| 220                   |                        |               | 25.59                | 3                    | 19.41                | 1720     | .44                  | .70                                          |

# VENTILATION

## 1.50 Prop (Cont.)

| <u>Ros<sup>+</sup></u> | <u>Nbr</u> | <u>Area</u> | <u>V<sub>av</sub></u> | <u>F<sub>r</sub></u> | <u>T<sub>s</sub></u> | <u>N</u> | <u>K<sub>r</sub></u> | <u>K<sub>r</sub><br/>K<sub>av</sub></u> |
|------------------------|------------|-------------|-----------------------|----------------------|----------------------|----------|----------------------|-----------------------------------------|
| 221                    | 12.25      | 195         | 4.28                  | .52                  |                      | 10       | .54                  | .86                                     |
| 222                    |            |             | 5.42                  | .60                  |                      | 342      | .62                  | .98                                     |
| 223                    |            |             | 5.33                  | .65                  |                      | 863      | .64                  | 1.02                                    |
| 224                    |            |             | 18.98                 | 2.31                 |                      | 143      | .57                  | .81                                     |
| 225                    |            |             | 20.03                 | 2.44                 |                      | 503      | .49                  | .78                                     |
| 226                    |            |             | 10.26                 | 1.25                 |                      | 458      | .55                  | .87                                     |
| 227                    |            |             | 9.23                  | 1.00                 |                      | 1257     | .44                  | .70                                     |
| 234                    |            |             | 4.22                  | .51                  |                      | 643      | .50                  | .79                                     |
| 235                    |            |             | 4.85                  | .59                  |                      | 662      | .53                  | 1.00                                    |
| 236                    |            |             | 18.42                 | 2.24                 |                      | 1875     | .51                  | .81                                     |
| 237                    |            |             | 9.06                  | 1.10                 |                      | 520      | .49                  | .78                                     |
| 238                    |            |             | 21.92                 | 2.67                 |                      | 2412     | .38                  | .54                                     |
| 239                    |            |             | 15.51                 | 1.89                 |                      | 1678     | .53                  | .84                                     |
| 240                    |            |             | 20.05                 | 2.44                 |                      | 1572     | .48                  | .78                                     |
| 241                    |            |             | 9.25                  | 1.13                 |                      | 1126     | .52                  | .83                                     |
| 242                    |            |             | 9.81                  | .95                  |                      | 1215     | .45                  | .71                                     |
| 243                    |            |             | 5.4                   | .63                  |                      | 795      | .49                  | .78                                     |
| 244                    | 12.25      | 33'         | 2.67                  | .33                  |                      | 637      | .51                  | .81                                     |
| 245                    |            |             | 4.15                  | .55                  |                      | 527      | .51                  | .97                                     |
| 246                    |            |             | 4.55                  | .55                  |                      | 371      | .60                  | .95                                     |
| 247                    |            |             | 21.59                 | 2.63                 |                      | 1824     | .48                  | .68                                     |
| 248                    |            |             | 24.31                 | 3.02                 |                      | 2116     | .41                  | .67                                     |
| 249                    |            |             | 10.71                 | 1.30                 |                      | 1051     | .52                  | .83                                     |
| 250                    |            |             | 9.5                   | .91                  |                      | 776      | .42                  | .68                                     |

$$F_r = \frac{1.47 V_{av}}{\sqrt{(32.2)(5.15)}} = 1038.5 \text{ } V_{av}$$

| <u>V<sub>av</sub></u> | <u>F<sub>r</sub></u> |
|-----------------------|----------------------|
| 10                    | .67                  |
| 15                    | .73                  |
| 20                    | 1.07                 |
| 25                    | 2.21                 |

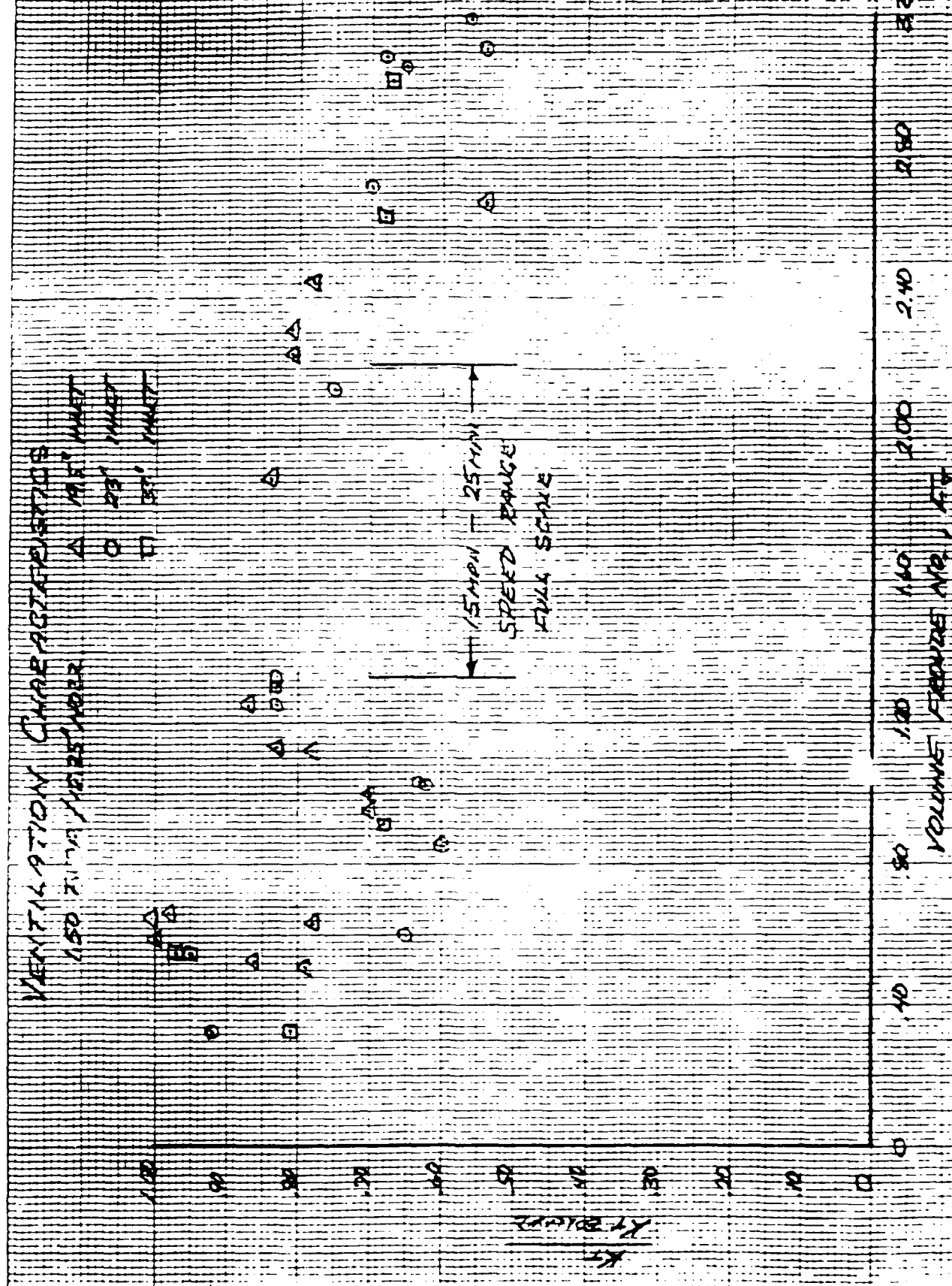
## VENTILATION CHARACTERISTICS

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APPENDIX D

## ESTIMATED INLET LOSSES

### SUMMARY

|                         |              |
|-------------------------|--------------|
| ENTRANCE                | 1.5825'      |
| INTAKE FRICTION + BEND  | 1.0149       |
| SHAFT                   | .4209        |
| TRANSITION              | .9402        |
| BEARING TUBE (FRICTION) | .0384        |
| PISTON TUBE (FRICTION)  | .2079        |
| STRUTS (PROG.)          | .1246        |
| STRUTS (INTERFERENCE)   | <u>.0060</u> |

$$H_{L_I} = 4.3352'$$

$$K = \frac{H_{L_I}}{Q^2} = \frac{4.3352}{(40)^2} = .0027$$

$$H_{L_I} = .0027 Q^2$$

## ESTIMATED INLET LOSSES

### ENTRANCE

$$Q = \text{NOV. FLOW RATE} = 40 \text{ FT}^3/\text{SEC}$$

$$A = \text{ENTRANCE AREA} = (14)(19.5)/144 = 1.90 \text{ FT}^2$$

$$V = \text{ENTRANCE VELOCITY} = \frac{Q}{A} = \frac{40}{1.90} = 21.05 \text{ FT/SEC}$$

$$K = \text{LOSS COEFF.} = .23$$

$$HL = \frac{KV^2}{2g} = \frac{(.23)(21.05)^2}{2(32.2)} = 1.5425'$$

### INTAKE FRICTION + BEND

$$Q = 40 \text{ FT}^3/\text{SEC.}$$

$$A = \text{INLET AREA} = (14)(14)/144 = 1.36 \text{ FT}^2$$

$$V = \text{INLET VELOCITY} = Q/A = 40/1.36 = 29.41 \text{ FT/SEC.}$$

$$d_e = \text{EQUIV. INLET DIAM} = \frac{4A}{\pi(14+14)/12} = \frac{4(1.36)^{1/2}}{\pi(14+14)} = 1.17'$$

$$R_e = \frac{Vd_e}{\nu} = \frac{(29.41)(1.17)}{1.24 \times 10^{-5}} = 2.77 \times 10^6$$

$$e = \text{ROUGHNESS} = .00005'$$

(SINCE DIAMETER = 14 IN.)

$$\frac{e}{d_e} = .00005' / 1.17 = .00000427$$

$$f = \text{FRICTION FACTOR} = .0079$$

$$L_1 = \text{INTAKE LENGTH} = 11/12 = .92'$$

$$L_2 = \text{EQUIV. LENGTH OF BEND} = \frac{L}{D} d_e \left( \frac{K}{90} \right) = (16)(1.17) \left( \frac{35}{90} \right) = 8.01'$$

$$L = \text{TOT. EQUIV. LENGTH} = L_1 + L_2 = .92' + 8.01' = 8.93'$$

$$HL = f \left( \frac{L}{d_e} \right) \left( \frac{V^2}{2g} \right) = .0079 \left( \frac{8.93}{1.17} \right) \frac{(29.41)^2}{2(32.2)} = 10.149'$$

## ESTIMATED NLE-LOSS

### SHAFT

$$C_D = \text{DRAG COEFF. DUE TO SHAFT FLOW} = 1.1 \text{ ft}^2 \text{ ft}^2 = 1.1 \text{ ft}^2 \text{ ft}^2 = .24$$

$$V = \text{WATER VELOCITY} = 27.41 \text{ ft/sec}$$

$$L = \text{SHAFT LENGTH} = 1.42'$$

$$d = \text{SHAFT DIAM} = 1.0/2 = .5'$$

$$D = \text{SHAFT DRAG} = C_D \times \frac{1}{2} \rho V^2 L = .24 \times \left(\frac{1.94}{2}\right) (27.41)^2 (1.42) = 35.34'$$

$$N_L = \frac{D}{A} = \frac{35.34}{1.94 \times 1.42} = .4207'$$

### TRANSITION

$$Q = 40 \text{ ft}^3/\text{sec}$$

$$A = \text{AREA AT SMALL END} = (.96)(.78)(14.12)/44 = 1.0434 \text{ ft}^2$$

$$V = \text{VELOCITY AT SMALL END} = Q/A = 40/1.0434 = 38.31 \text{ ft/sec}$$

$$C_L = \text{LIFT COEFF.} = 1.0$$

$$K = \text{CURVATURE} = \frac{1}{R} = \frac{1}{14.12} = .0712$$

$$N_L = K \frac{L^2}{V} = (.0712)(38.31)^2 / 1.0434 = .2522$$

### BEARING TUBE (CORRECTION)

$$V = 38.31 \text{ ft/sec}$$

$$L = \text{TUBE LENGTH} = 1.42'$$

$$K_C = \frac{V L}{1.42 \times 10^5} = \frac{38.31 \times 1.42}{1.42 \times 10^5} = .00385$$

$$C_D = .00385$$

$$D = \text{TUBE DRAG} = C_D \times \frac{1}{2} \rho V^2 L = .00385 \times \left(\frac{1.94}{2}\right) (38.31)^2 (1.42) = 3.26'$$

$$N_L = \frac{D}{A} = \frac{3.26}{1.94 \times 1.42} = .0784'$$

## ESTIMATED FRICTION LOSSES

### BORING TUBE (FRIC TAIL)

$$A_o = (2.15)(2^2 - 1.5^2)/4 = .0095 \text{ ft}^2$$

$$V = 36.34 \text{ ft/sec}$$

$$C_D = 1.00$$

$$D = C_D A_o \rho_L V^2 = (1.00)(.0095)(\frac{1.9}{4})(36.3)^2 = 13.55''$$

$$HL = \frac{D}{\rho g A} = \frac{13.55}{(1.94)(32.2)(.0095)} = .2079'$$

### STRUTS (PROFILE)

$$A = 1.0434 \text{ ft}^2$$

$$V = 38.34 \text{ ft/sec}$$

$$C = \text{STRUT CHORD} = 3'' = .25'$$

$$Re = \frac{V_c}{\mu} = \frac{(38.34)(.25)}{1.24 \times 10^{-5}} = 7.73 \times 10^5$$

$$C_f = .0046$$

$$V_c = .3125/3 = .1042$$

$$C_s = 2(2.5)(.1042)(1.124) = 2(2.5)(.1042)(1.124) = .0122$$

$$C = \text{STRUT DIAMETER COEFF} = 2(3)(.25)(.25)/4 = .4667 \text{ ft}^2$$

$$D = \text{STRUT DRAG} = C_s S \rho_L V^2 = (2.5)(4.2)(\frac{1.9}{4})(38.3)^2 = 7.12''$$

$$HL = \frac{D}{\rho g A} = \frac{7.12}{(1.94)(32.2)(1.0434)} = .246'$$

## ESTIMATED INLET LOSSES

### STRUT (INTERFERENCE)

$$A = 1.0434 \text{ ft}^2$$

$$V = 38.34 \text{ ft/sec}$$

$$K = \text{Strut Interference} = 1.325 = .0265' \quad \frac{1}{K} = .1042$$

$$C_D = .25 \frac{1}{K} - \frac{2003}{(V/C)^4} = (.25)(.1042) - \frac{2003}{(38.34)^4} = .0535$$

$$D = \text{Inlet Loss} = 85 + 9.1 - 2(1 - (.0265)^2)(\frac{1}{2})(38.34)^2 = .3821'$$

$$H_L = \frac{D}{K \cdot g \cdot A} = \frac{.3821}{1.94 \cdot 1.0434} = .2065'$$

## ESTIMATED CASING LOSS

### CASING

$$Q = 40 \text{ ft}^3/\text{sec}$$

$$A = \text{CASING AREA} = (785) \left( \frac{14.12}{12} \right)^2 = 1.087 \text{ ft}^2$$

$$V = Q/A = 40/1.087 = 36.80 \text{ ft/sec}$$

$$d = \text{CASING DIAM.} = 14.12 = 1.1767'$$

$$Re = \frac{Vd}{\nu} = \frac{(36.80)(1.1767)}{1.2 \times 10^{-5}} = 349 \times 10^6$$

$$e = .000005'$$

$$e/d = .000005/1.1767 = .00000425$$

$$f = .0097$$

$$L = \text{CASING LENGTH} = 1.33'$$

$$HL = f \left( \frac{L}{2} \right) \frac{V^2}{2g} = (.0097) \left( \frac{1.33}{2} \right) \frac{(36.80)^2}{2(32.2)} = .2319'$$

$$k = \frac{HL}{Q} = \frac{.2319}{(40)^2} = .000145$$

$$HL = .000145 Q^2$$

## ESTIMATED NOZZLE LOSS

$$HL_s = \frac{V_s^2}{2g} (1+K)$$

$$V_s = Q/A_s$$

$$Q = 40 \text{ cfs/sec}$$

$$A_s = .025 d_s^2$$

$$d_s = D \left( \frac{d}{D} \right)$$

$$\frac{d_s}{D} = f \left( \frac{d}{D} \right)$$

$$d = 12.00''$$

$$D = 14.12''$$

$$\frac{d}{D} = \frac{12.00}{14.12} = .8499$$

$$\frac{d_s}{D} = .805$$

$$d_s = (14.12)(.805) = 11.37'' = .9472'$$

$$A_s = (.785)(.9472)^2 = .7043 \text{ ft}^2$$

$$V_s = 40/.7043 = 56.81 \text{ ft/sec}$$

$$K = f \left( \frac{L}{D} \right)$$

$$\mathcal{L} = .785 \mathcal{L}^2 = .785(12)^2 = 113.04 \text{ ft} = .05 \text{ ft}^2$$

$$\mathcal{L} = .785 \mathcal{L}^2 = .785(14.12)^2 = 153.57 \text{ ft} = .089 \text{ ft}^2$$

$$\frac{\mathcal{L}}{A} = \frac{.785}{.7043} = .0328$$

$$K = .0328$$

$$HL_s = \frac{(56.81)^2}{2(32.2)} (1 + .0328) = 52.18'$$

$$f = \frac{HL}{Q} = \frac{52.18}{140} = .0328$$

$$HL_s = .0328 Q^2$$

## NOZZLE CHARACTERISTICS

### JET DIAM.

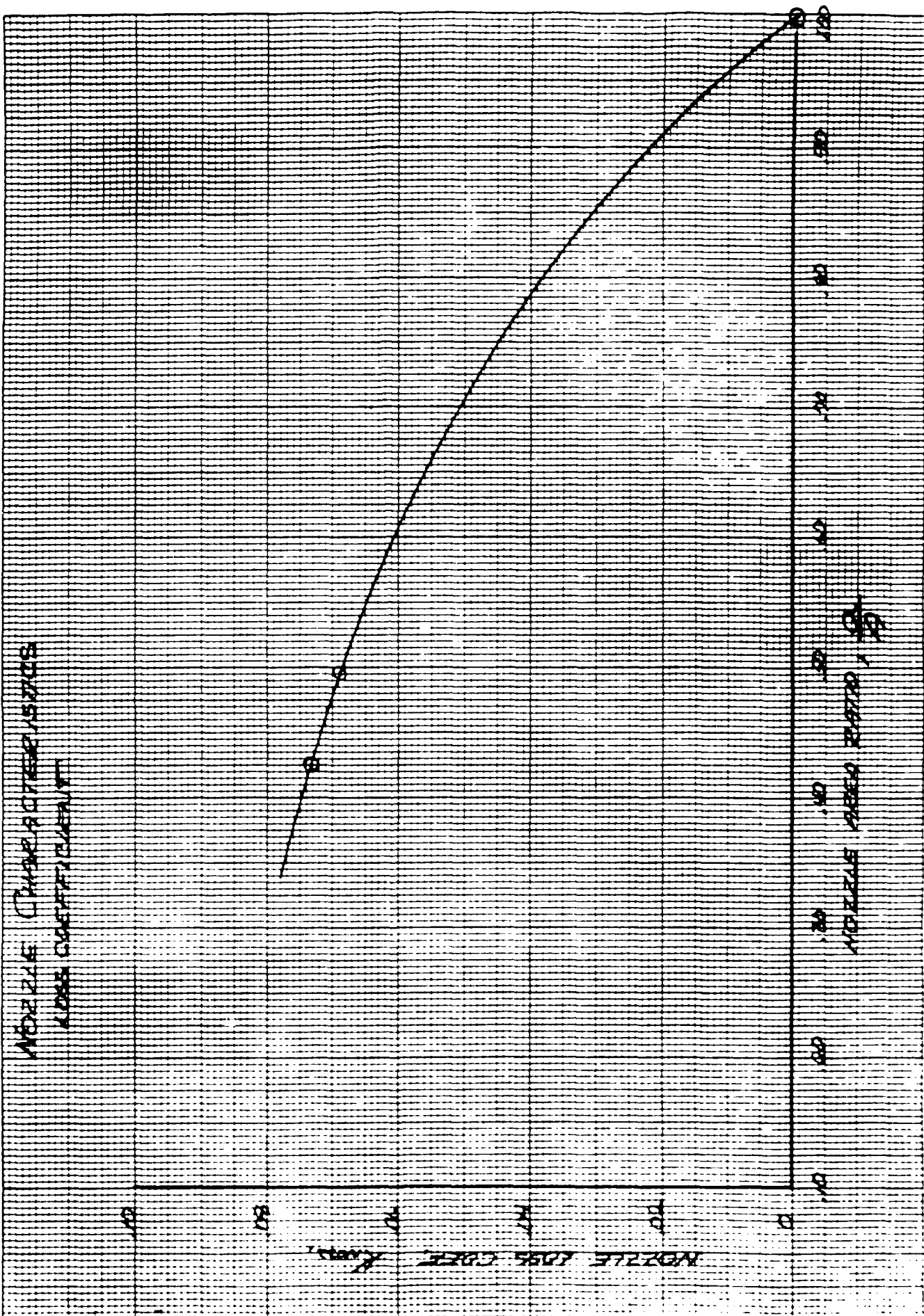
| <u>No.</u> | <u><math>\frac{d}{D}</math></u> | <u><math>\frac{d_j}{D}</math></u> |
|------------|---------------------------------|-----------------------------------|
| 1          | .5081                           | .4643                             |
| 2          | .5686                           | .5455                             |
| 3          | .6508                           | .6032                             |
| 4          | .7027                           | .6575                             |
| None       | 1.00                            | 1.00                              |

### LOSS COEF.

| <u>No.</u> | <u><math>\frac{d}{D}</math></u> | <u><math>\frac{a}{A}</math></u> | <u>K</u> |
|------------|---------------------------------|---------------------------------|----------|
| 3          | .6508                           | .4245                           | .0793    |
| 4          | .7027                           | .4940                           | .0688    |
| None       | 1.00                            | 1.00                            | 0        |



NOZZLE CHARACTERISTICS  
LOSS COEFFICIENT



ESTIMATED INLET PRESSURE RECOVERY

$$H_0 = RPR \frac{V_0^2}{2g}$$

$$RPR = 1.00$$

$$H_0 = (1.00) \frac{V_0^2}{2(32.2)} = .0155 V_0^2$$

AD-A153 266

DESIGN PROCEDURES FOR LOW SPEED WATERJETS SUITABLE FOR  
APPLICATION IN AMP. (U) STEVENS INST OF TECH HOBOKEN NJ  
DAVIDSON LAB J K ROPER MAR 85 SIT-DL-85-9-2518

2/2

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F/G 21/7

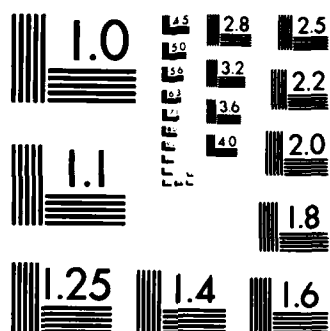
NL



END

FORM

DTF



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

### ESTIMATED PUMP HEAD REQUIRED

$$H_{REQ} = H_{L_I} + H_{L_e} + H_{L_J} - H_0$$

$$H_{L_I} = .0027 Q^2$$

$$H_{L_e} = .000145 Q^2$$

$$H_{L_J} = .0328 Q^2$$

$$H_0 = .0155 V_0^2$$

$$\begin{aligned} H_{REQ} &= (.0027 + .000145 + .0328) Q^2 - .0155 V_0^2 \\ &= .0356 Q^2 - .0155 V_0^2 \end{aligned}$$

## ESTIMATED CAVITATION LIMITS

$$\sigma = \frac{H_{fs} - H_{vap}}{V_f^2 / 2g}$$

$$H_{fs} = H_{arm} + h_f - H_{fs} - \frac{V_f^2}{2g}$$

$$H_{arm} = 33.07'$$

$$H_o = .0155 V_o^2$$

$$H_{fs} = .0027 Q^2$$

$$\frac{V_f^2}{2g} = \frac{Q^2}{(1.0434)^4 \cdot 2(32.2)} = .0143 Q^2$$

$$H_{fs} = 33.07 + .0155 V_o^2 - .0027 Q^2 - .0143 Q^2$$

$$= 33.07 + .0155 V_o^2 - .017 Q^2$$

$$H_{vap} = 1.00'$$

$$\sigma = \frac{33.07 + .0155 V_o^2 - .017 Q^2 - 1}{.0143 Q^2} = \frac{32.07 + .0155 V_o^2 - .017 Q^2}{.0143 Q^2}$$

$$.0143 Q^2 \sigma + .017 Q^2 = 32.07 + .0155 V_o^2$$

$$Q^2 = \frac{32.07 + .0155 V_o^2}{.0143 \sigma + .017}$$

$$\text{Suggested } \sigma_{min} = .75$$

## ESTIMATED PROPELLER CHARACTERISTICS

### PUMP EFFICIENCY (1.50 PPM / 12.25 NDL)

ESTIMATED FROM CURVES OF  $\lambda_p$ -VS- $\sigma$  AND  $\lambda_p$ -VS-SHP

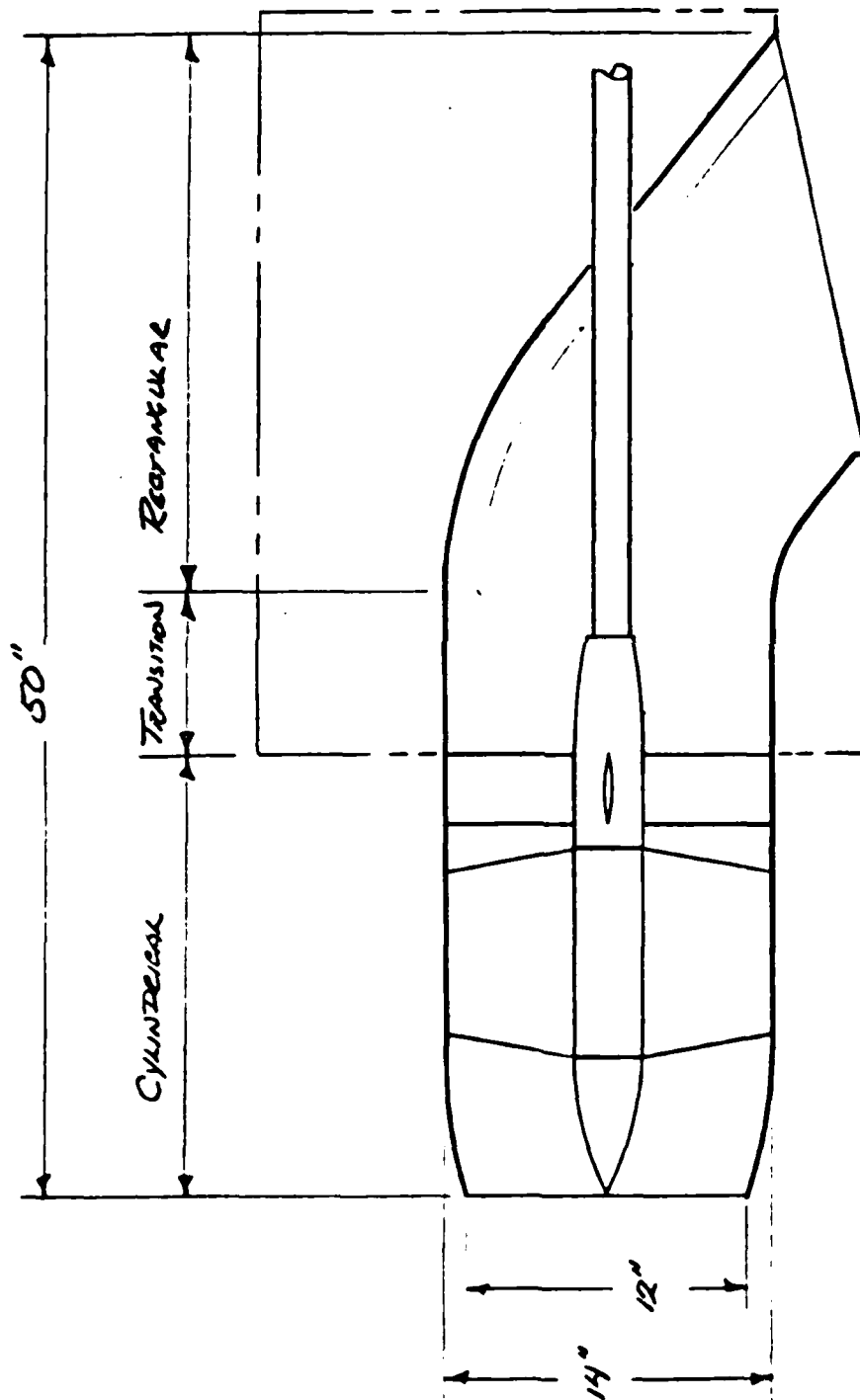
USE  $\lambda_p = .72$

### PROP. ADVANCE COEF (1.50 PPM / 12.25 NDL)

ESTIMATED FROM CURVES OF  $J$ -VS- $\sigma$  AND  $J$ -VS-SHP

USE  $J = .82$

APPENDIX E



14" PUMP  
INSTALLED IN .55 SCALE MODEL

## SHP REQUIRED

### CALCULATION NOTES

$$V_{max} = \text{CRAFT SPEED} \sim \text{MAX (NOMINAL VALUES)}$$

$$V_0 = 1.47 (V_{max})$$

$$Q = \text{FLOW RATE} \sim \text{FT}^3/\text{SEC (NOMINAL VALUES)}$$

$$H_p = \text{REQD. PUMP HEAD} = .0356 Q^2 - .0155 V_0^2$$

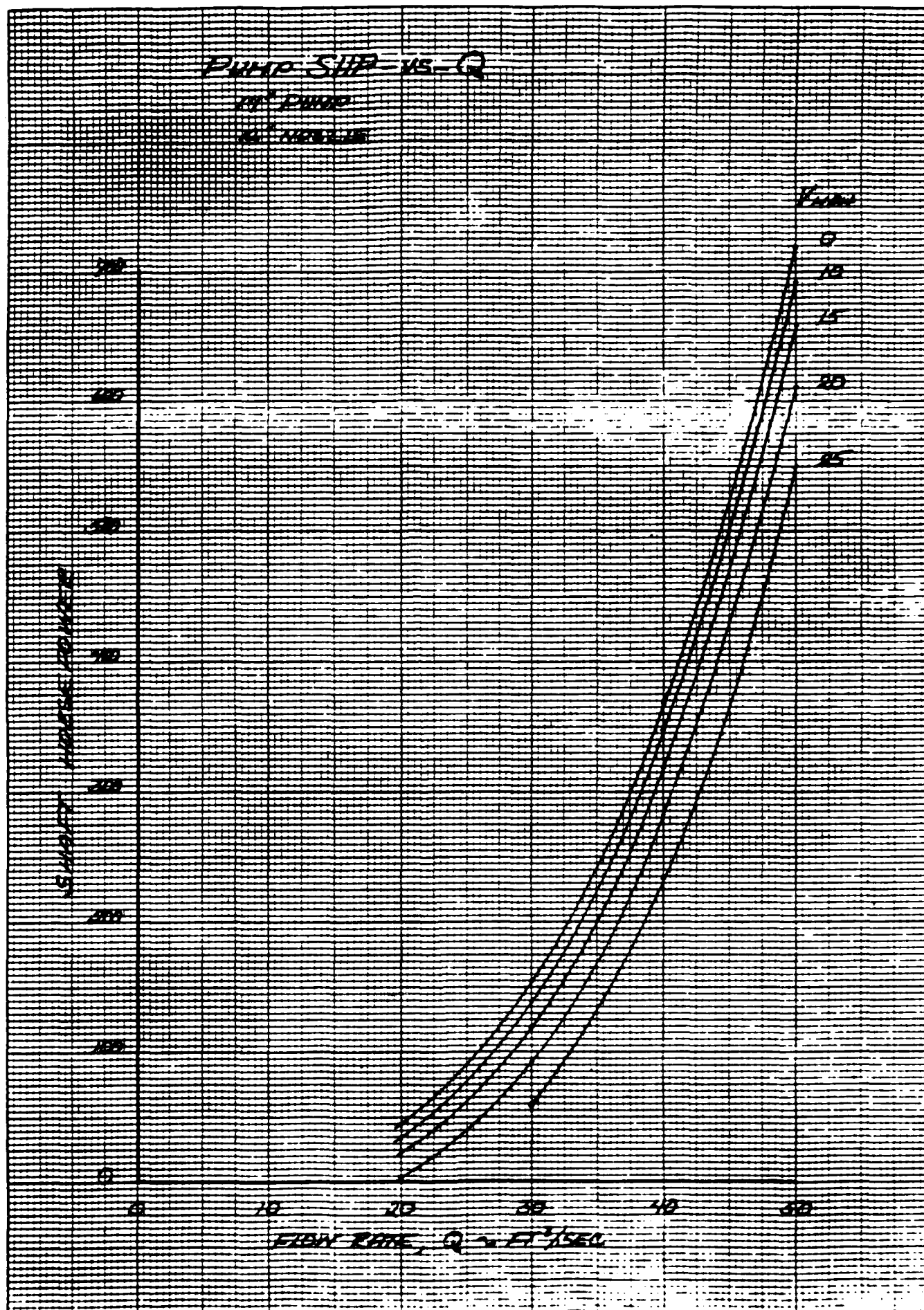
$$\eta_p = \text{PUMP EFFICIENCY} = .72$$

$$SHP = \text{POWER REQD. BY PUMP} = \frac{P \gamma Q H_p}{550 \eta_p}$$

# SHP REQUIRED

## CALCULATION

| <u>V<sub>WPM</sub></u> | <u>V<sub>0</sub></u> | <u>Q</u> | <u>L<sub>p</sub></u> | <u>λ<sub>p</sub></u> | <u>SHP</u> |
|------------------------|----------------------|----------|----------------------|----------------------|------------|
| 0                      | 0                    | 20       | 17.24                | .72                  | 46         |
|                        |                      | 30       | 32.24                |                      | 155        |
|                        |                      | 40       | 56.96                |                      | 368        |
|                        |                      | 50       | 89.00                |                      | 719        |
| 10                     | 14.70                | 20       | 10.89                | .72                  | 35         |
|                        |                      | 30       | 28.69                |                      | 139        |
|                        |                      | 40       | 53.61                |                      | 347        |
|                        |                      | 50       | 85.65                |                      | 692        |
| 15                     | 22.05                | 20       | 6.70                 | .72                  | 22         |
|                        |                      | 30       | 24.50                |                      | 119        |
|                        |                      | 40       | 49.42                |                      | 319        |
|                        |                      | 50       | 81.46                |                      | 658        |
| 20                     | 29.40                | 20       | .64                  | .72                  | 3          |
|                        |                      | 30       | 18.64                |                      | 91         |
|                        |                      | 40       | 43.56                |                      | 282        |
|                        |                      | 50       | 75.60                |                      | 611        |
| 25                     | 36.75                | 20       | -6.69                | .72                  | -          |
|                        |                      | 30       | 11.11                |                      | 54         |
|                        |                      | 40       | 33.53                |                      | 233        |
|                        |                      | 50       | 68.07                |                      | 520        |



## SYSTEM PERFORMANCE (Power Limit)

### CALCULATION NOTES

$$V_{MAN} = \text{CRAFT SPEED} \sim \text{KNOTS} \quad (\text{NOMINAL VALUES})$$

$$V_0 = 1.47 V_{MAN}$$

$$\text{SHP} = \text{POWER TO PROP} \sim \text{HP} \quad (\text{NOMINAL VALUES})$$

$$Q = \text{FLOW RATE} \sim \text{FT}^3/\text{SEC} \quad (\text{FROM SHIP PROP. CURVES})$$

$$A_j = \text{JET AREA} \sim \text{FT}^2$$

$$V_j = \text{JET VELOCITY} = \frac{Q}{A}$$

$$T_j = \text{JET THRUST} = \rho Q (V_j - V_0)$$

$$\text{OPE} = \text{PROPULSIVE COEFF.} = \frac{T_j V_0}{\text{SHP SHIP}}$$

$$J = \text{PROP ADVANCE COEF.} = .82$$

$$N = \text{PROP RPM} = 49.29 \frac{Q}{J}$$

# SYSTEM PERFORMANCE (POWER LIMIT)

## CALCULATION

| <u>V<sub>max</sub></u> | <u>V<sub>0</sub></u> | <u>SHP</u> | <u>Q</u> | <u>A<sub>1</sub></u> | <u>V<sub>1</sub></u> | <u>T<sub>1</sub></u> | <u>OPC</u> | <u>J</u> | <u>N</u> |
|------------------------|----------------------|------------|----------|----------------------|----------------------|----------------------|------------|----------|----------|
| 0                      | 0                    | 100        | 25.8     | .1043                | 36.63                | 1676                 | —          | .82      | 1551     |
|                        |                      | 150        | 29.1     |                      | 42.17                | 2489                 | —          |          | 1785     |
|                        |                      | 200        | 32.9     |                      | 46.71                | 3054                 | —          |          | 1978     |
|                        |                      | 250        | 35.4     |                      | 50.26                | 3536                 | —          |          | 2128     |
|                        |                      | 300        | 37.6     |                      | 53.39                | 3990                 | —          |          | 2260     |
| 10                     | 14.70                | 100        | 27.1     |                      | 38.48                | 1281                 | .342       | .82      | 1629     |
|                        |                      | 150        | 30.8     |                      | 43.23                | 1777                 | .317       |          | 1851     |
|                        |                      | 200        | 33.8     |                      | 47.99                | 2236                 | .299       |          | 2032     |
|                        |                      | 250        | 36.3     |                      | 51.54                | 2658                 | .284       |          | 2182     |
|                        |                      | 300        | 38.4     |                      | 54.62                | 3039                 | .271       |          | 2308     |
| 15                     | 20.25                | 100        | 28.6     |                      | 40.61                | 1055                 | .423       | .82      | 1719     |
|                        |                      | 150        | 32.2     |                      | 45.22                | 1515                 | .405       |          | 1936     |
|                        |                      | 200        | 35.1     |                      | 49.84                | 1939                 | .389       |          | 2110     |
|                        |                      | 250        | 37.4     |                      | 53.10                | 2308                 | .370       |          | 2248     |
|                        |                      | 300        | 39.4     |                      | 55.94                | 2654                 | .355       |          | 2368     |
| 20                     | 29.40                | 100        | 30.7     |                      | 43.59                | 866                  | .463       | .82      | 1845     |
|                        |                      | 150        | 34.0     |                      | 48.27                | 1275                 | .454       |          | 2044     |
|                        |                      | 200        | 36.7     |                      | 52.11                | 1657                 | .443       |          | 2206     |
|                        |                      | 250        | 38.8     |                      | 55.09                | 1981                 | .424       |          | 2332     |
|                        |                      | 300        | 40.7     |                      | 57.09                | 2297                 | .409       |          | 2446     |
| 25                     | 36.25                | 100        | 33.0     |                      | 46.46                | 663                  | .443       | .82      | 1984     |
|                        |                      | 150        | 36.0     |                      | 51.11                | 1027                 | .458       |          | 2164     |
|                        |                      | 200        | 38.6     |                      | 54.61                | 1350                 | .403       |          | 2320     |
|                        |                      | 250        | 41.8     |                      | 57.93                | 1718                 | .459       |          | 2452     |
|                        |                      | 300        | 42.8     |                      | 60.77                | 2043                 | .455       |          | 2573     |

## SYSTEM PERFORMANCE (CAVITATION UNITS)

### CALCULATION NOTES

$\sigma$  = CAVITATION INDEX, BASED ON INLET AIR/WATER FLOW (SELECTED VALUES)

$V_{NPN}$  = CRAFT SPEED ~ MPH (NOMINAL VALUES)

$V_0$  = 1.47  $V_{NPN}$

$Q$  = FLOW RATE =  $\frac{32.07 + .0155 V_0^2}{.0143 \sigma + .017}$

$A_j$  = JET AREA ~ FT<sup>2</sup>

$V_j$  = JET VELOCITY =  $\frac{Q}{A_j}$

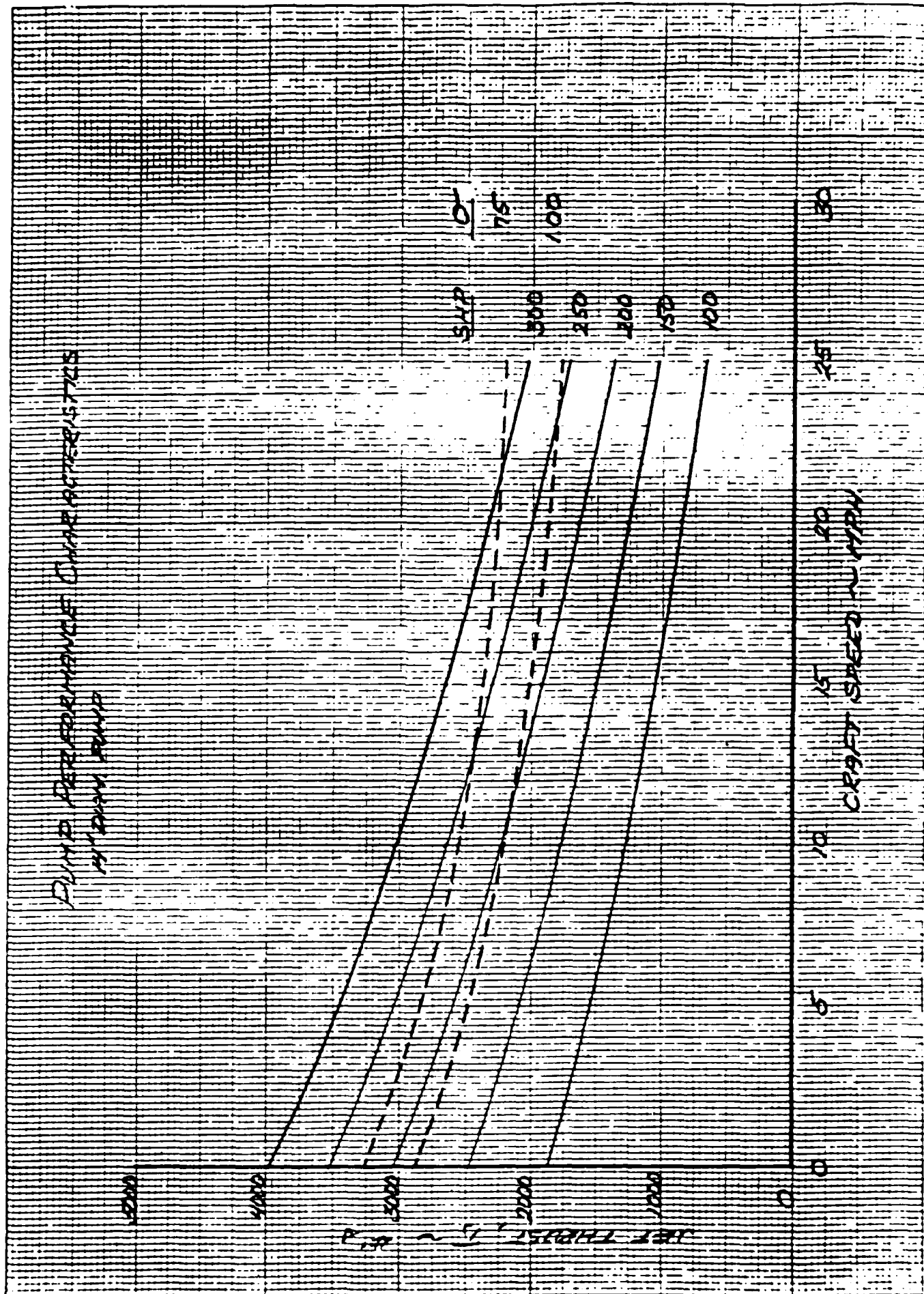
$T_j$  = JET THRUST =  $PQ(V_j - V_0)$

# SYSTEM PERFORMANCE (CAVITATION LIMIT)

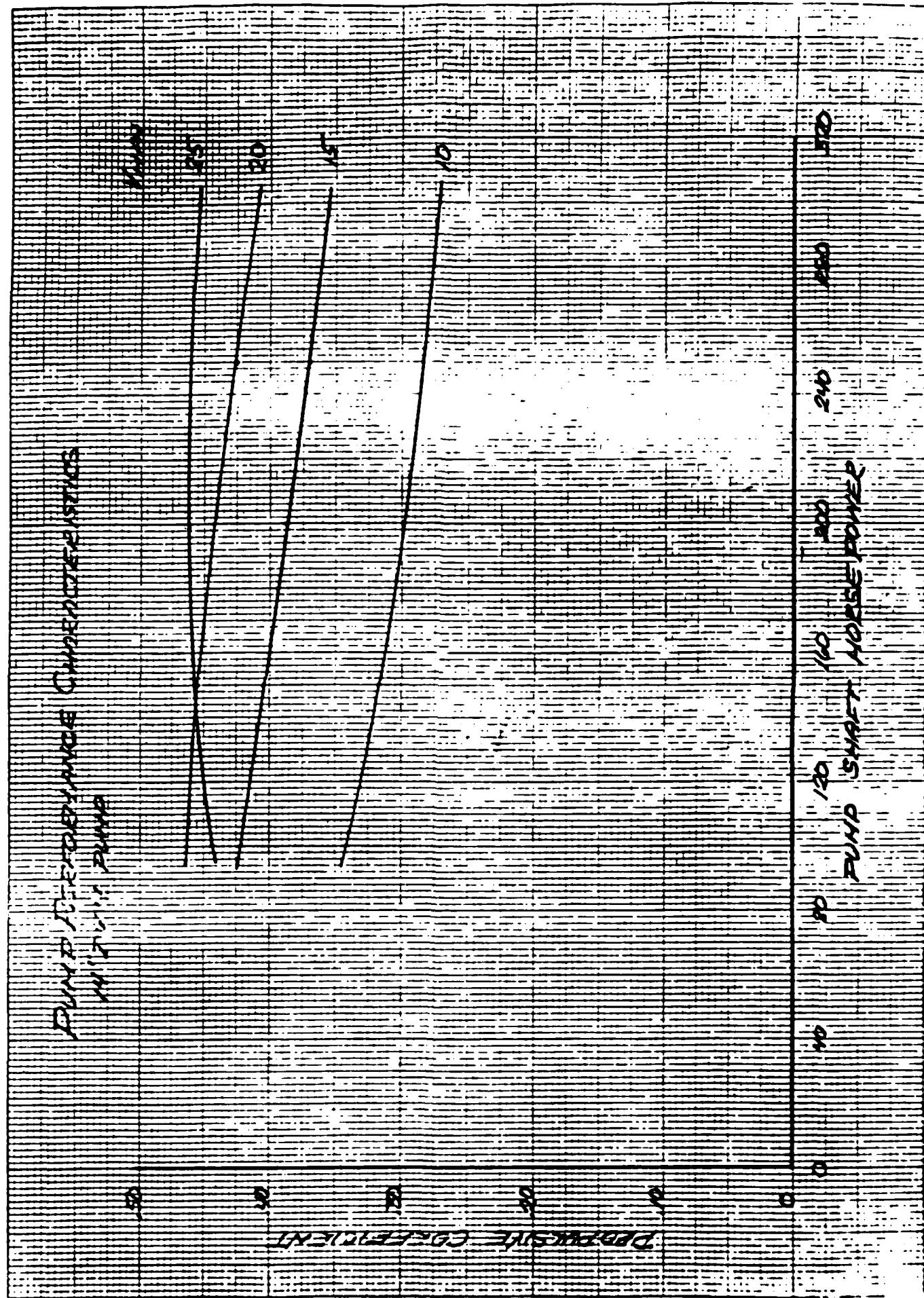
## CALCULATION

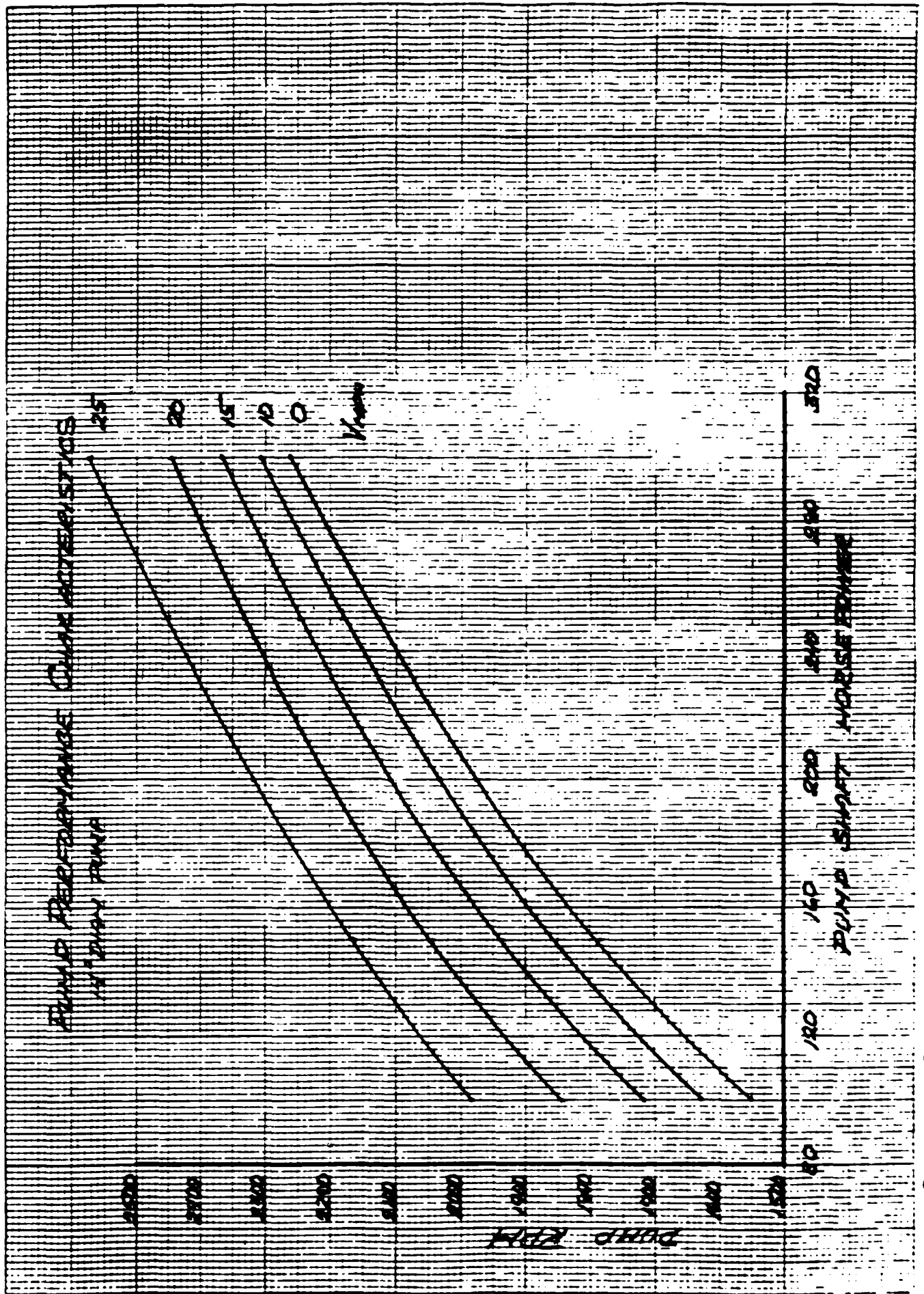
| <u><math>\sigma</math></u> | <u><math>V_{H2O}</math></u> | <u><math>V_0</math></u> | <u><math>Q</math></u> | <u><math>A_s</math></u> | <u><math>V_s</math></u> | <u><math>T</math></u> |
|----------------------------|-----------------------------|-------------------------|-----------------------|-------------------------|-------------------------|-----------------------|
| 1.00                       | 0                           | 0                       | 32.01                 | .7043                   | 45.45                   | 2892                  |
|                            | 10                          | 14.70                   | 33.64                 |                         | 47.76                   | 2210                  |
|                            | 15                          | 22.05                   | 35.57                 |                         | 50.57                   | 2012                  |
|                            | 20                          | 29.40                   | 38.11                 |                         | 54.12                   | 1872                  |
|                            | 25                          | 36.75                   | 41.15                 |                         | 58.43                   | 1773                  |
| .75                        | 0                           | 0                       | 34.01                 | .7043                   | 48.29                   | 3264                  |
|                            | 10                          | 14.70                   | 35.74                 |                         | 50.25                   | 2561                  |
|                            | 15                          | 22.05                   | 37.80                 |                         | 53.66                   | 2375                  |
|                            | 20                          | 29.40                   | 40.50                 |                         | 57.50                   | 2262                  |
|                            | 25                          | 36.75                   | 43.72                 |                         | 62.08                   | 2201                  |

# PUMP PERFORMANCE CHARACTERISTICS HYDRA PUMP

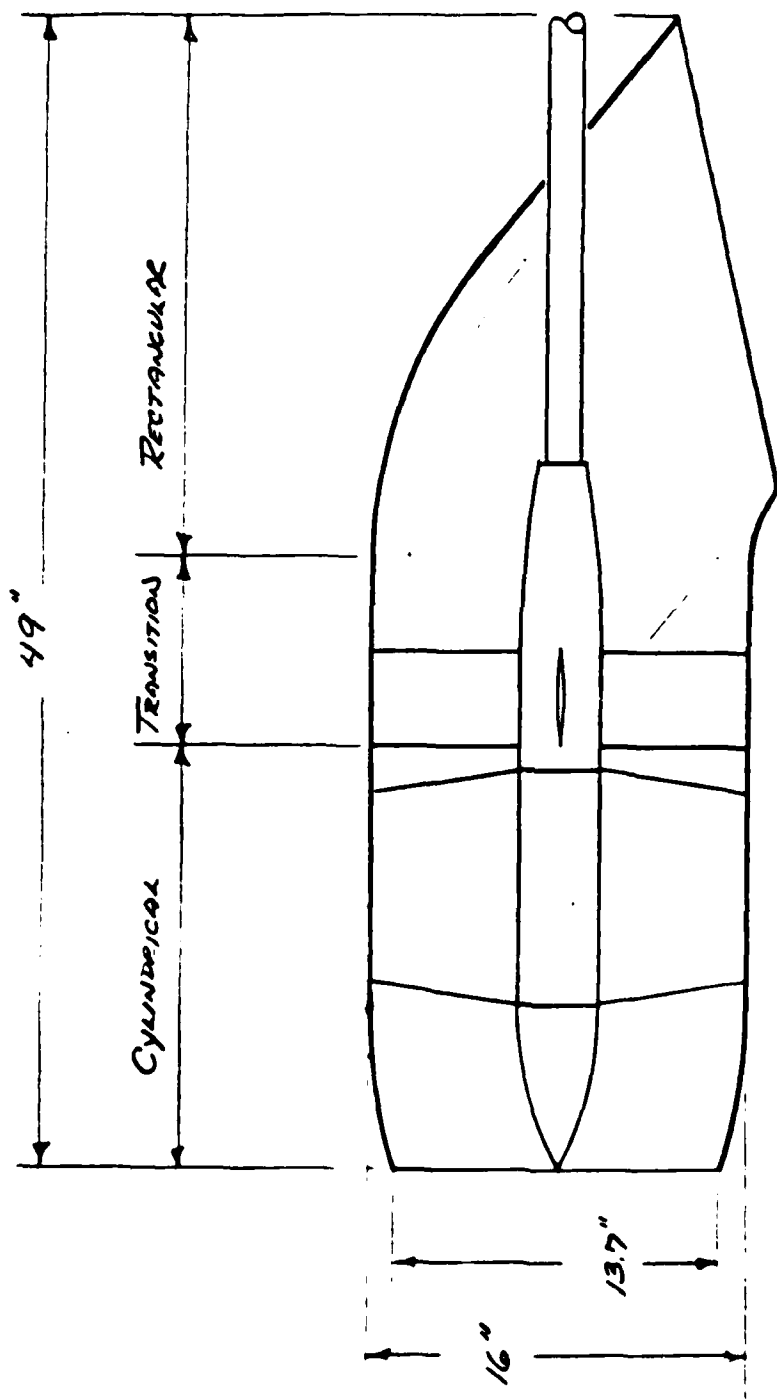


# PUMP PERFORMANCE CHARACTERISTICS WATER PUMP





APPENDIX F



PROPOSED PUMP - 1/6" DIAM.

## ESTIMATED PERFORMANCE (POWER LIMIT)

### CALCULATION NOTES

$V_{MAN}$  = CRAFT SPEED ~ MAN (NOMINAL VALUES)

$SHP_{14}$  = POWER TO 14" DUMP ~ HP (NOMINAL VALUES)

$SHP_{16}$  = POWER TO 16" DUMP =  $SHP_{14} \left(\frac{16}{14}\right)^2$

$T_{14}$  = JET THRUST, 14" DUMP ~  $T$  (FROM ESTIMATED PERFORMANCE CALCS, 14" DUMP)

$T_{16}$  = JET THRUST, 16" DUMP =  $T_{14} \left(\frac{16}{14}\right)^2$

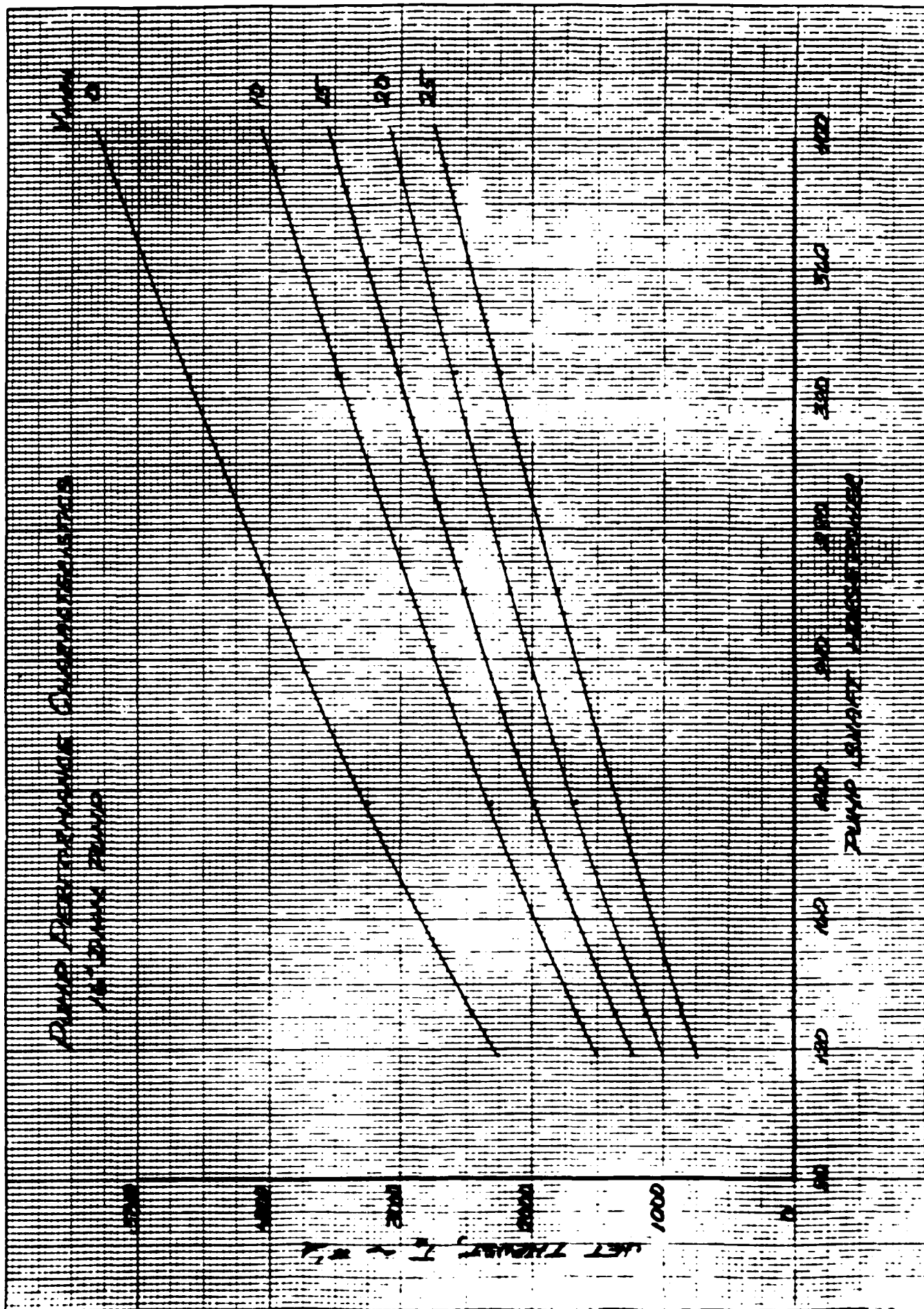
$N_{14}$  = PROP RPM, 14" DUMP

$N_{16}$  = PROP RPM, 16" DUMP =  $N_{14} \left(\frac{14}{16}\right)$

# ESTIMATED PERFORMANCE (POWER UNIT)

## CALCULATION

| <u>V<sub>MAN</sub></u> | <u>SHA<sub>N</sub></u> | <u>SHA<sub>6</sub></u> | <u>T<sub>N</sub></u> | <u>T<sub>6</sub></u> | <u>N<sub>N</sub></u> | <u>N<sub>6</sub></u> | <u>SHA<sub>6</sub></u> | <u>T<sub>6</sub></u> |
|------------------------|------------------------|------------------------|----------------------|----------------------|----------------------|----------------------|------------------------|----------------------|
| 0                      | 100                    | 131                    | 1878                 | 2453                 | 1551                 | 1357                 | 200                    | 3330                 |
|                        | 150                    | 196                    | 2489                 | 3257                 | 1785                 | 1562                 | 300                    | 4360                 |
|                        | 200                    | 261                    | 3054                 | 3989                 | 1978                 | 1731                 | 400                    | 5260                 |
|                        | 250                    | 327                    | 3536                 | 4618                 | 2128                 | 1862                 |                        |                      |
|                        | 300                    | 392                    | 3990                 | 5211                 | 2260                 | 1978                 |                        |                      |
| 10                     | 100                    | 131                    | 1281                 | 1673                 | 1629                 | 1425                 | 200                    | 2360                 |
|                        | 150                    | 196                    | 1777                 | 2320                 | 1857                 | 1620                 | 300                    | 3250                 |
|                        | 200                    | 261                    | 2236                 | 2920                 | 2032                 | 1778                 | 400                    | 4040                 |
|                        | 250                    | 327                    | 2658                 | 3472                 | 2182                 | 1909                 |                        |                      |
|                        | 300                    | 392                    | 3039                 | 3969                 | 2308                 | 2020                 |                        |                      |
| 15                     | 100                    | 131                    | 1055                 | 1378                 | 1719                 | 1504                 | 200                    | 2020                 |
|                        | 150                    | 196                    | 1515                 | 1979                 | 1936                 | 1694                 | 300                    | 2820                 |
|                        | 200                    | 261                    | 1939                 | 2533                 | 2110                 | 1846                 | 400                    | 3530                 |
|                        | 250                    | 327                    | 2308                 | 3015                 | 2248                 | 1967                 |                        |                      |
|                        | 300                    | 392                    | 2654                 | 3466                 | 2368                 | 2072                 |                        |                      |
| 20                     | 100                    | 131                    | 866                  | 1131                 | 1845                 | 1614                 | 200                    | 1720                 |
|                        | 150                    | 196                    | 1275                 | 1665                 | 2044                 | 1788                 | 300                    | 2430                 |
|                        | 200                    | 261                    | 1657                 | 2164                 | 2206                 | 1930                 | 400                    | 3060                 |
|                        | 250                    | 327                    | 1981                 | 2587                 | 2332                 | 2040                 |                        |                      |
|                        | 300                    | 392                    | 2297                 | 3000                 | 2446                 | 2140                 |                        |                      |
| 25                     | 100                    | 131                    | 663                  | 866                  | 1984                 | 1736                 | 200                    | 1350                 |
|                        | 150                    | 196                    | 1027                 | 1341                 | 2164                 | 1894                 | 300                    | 2080                 |
|                        | 200                    | 261                    | 1386                 | 1810                 | 2320                 | 2030                 | 400                    | 2720                 |
|                        | 250                    | 327                    | 1718                 | 2244                 | 2452                 | 2146                 |                        |                      |
|                        | 300                    | 392                    | 2043                 | 2668                 | 2573                 | 2251                 |                        |                      |



## ESTIMATED PERFORMANCE (CAVITATION LIMIT)

### CALCULATION NOTES

$V_{MAN}$  = CRAFT SPEED  $\sim$  MAN (NOMINAL VALUES)

$\sigma$  = CAVITATION INDEX (SELECTED VALUES)

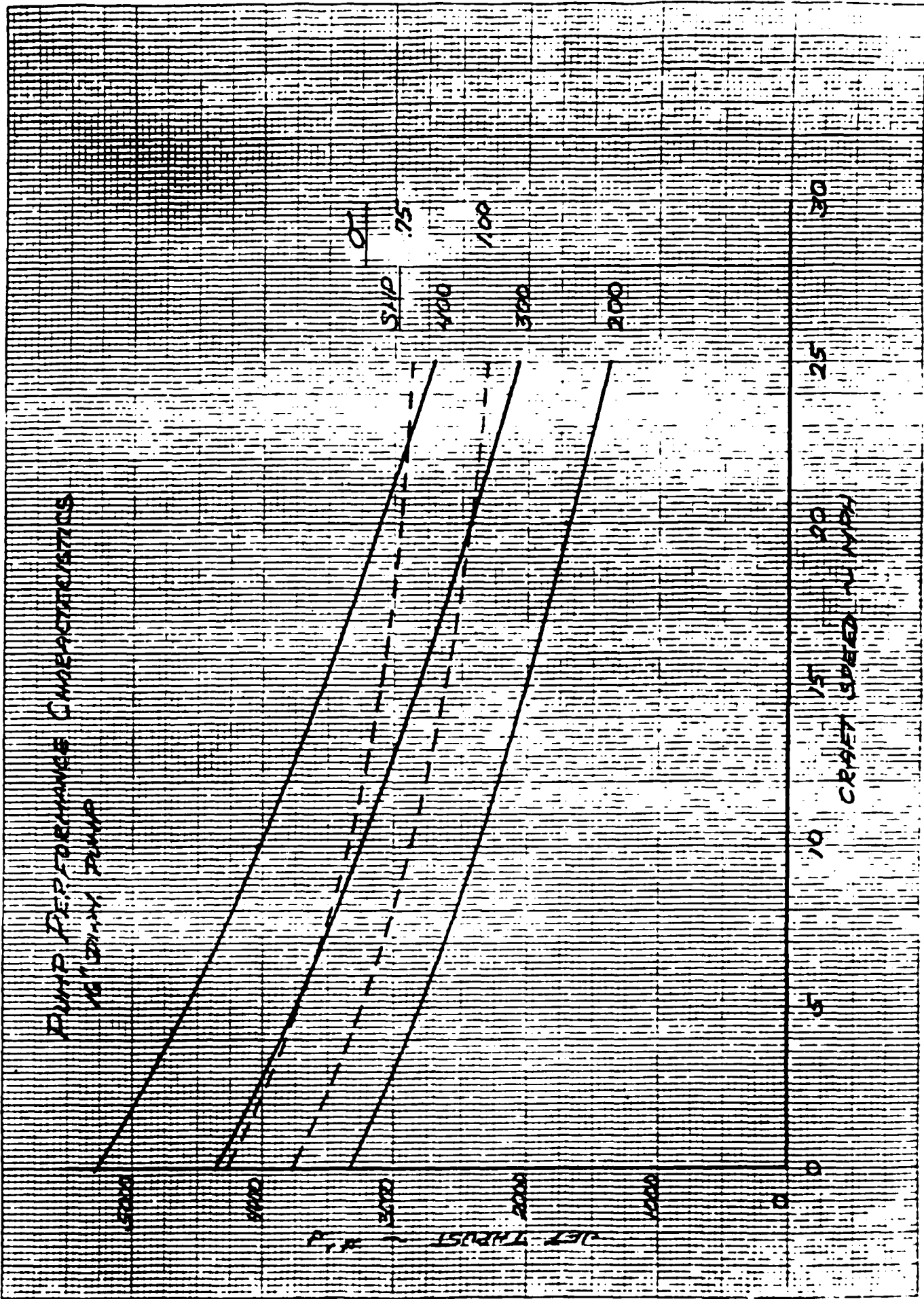
$T_{14}$  = JET THRUST, 14" PUMP  $\sim$  1 (FROM E.T. 225, 14" PUMP)

$T_{16}$  = JET THRUST, 16" PUMP =  $T_{14} \left( \frac{16}{14} \right)^2$

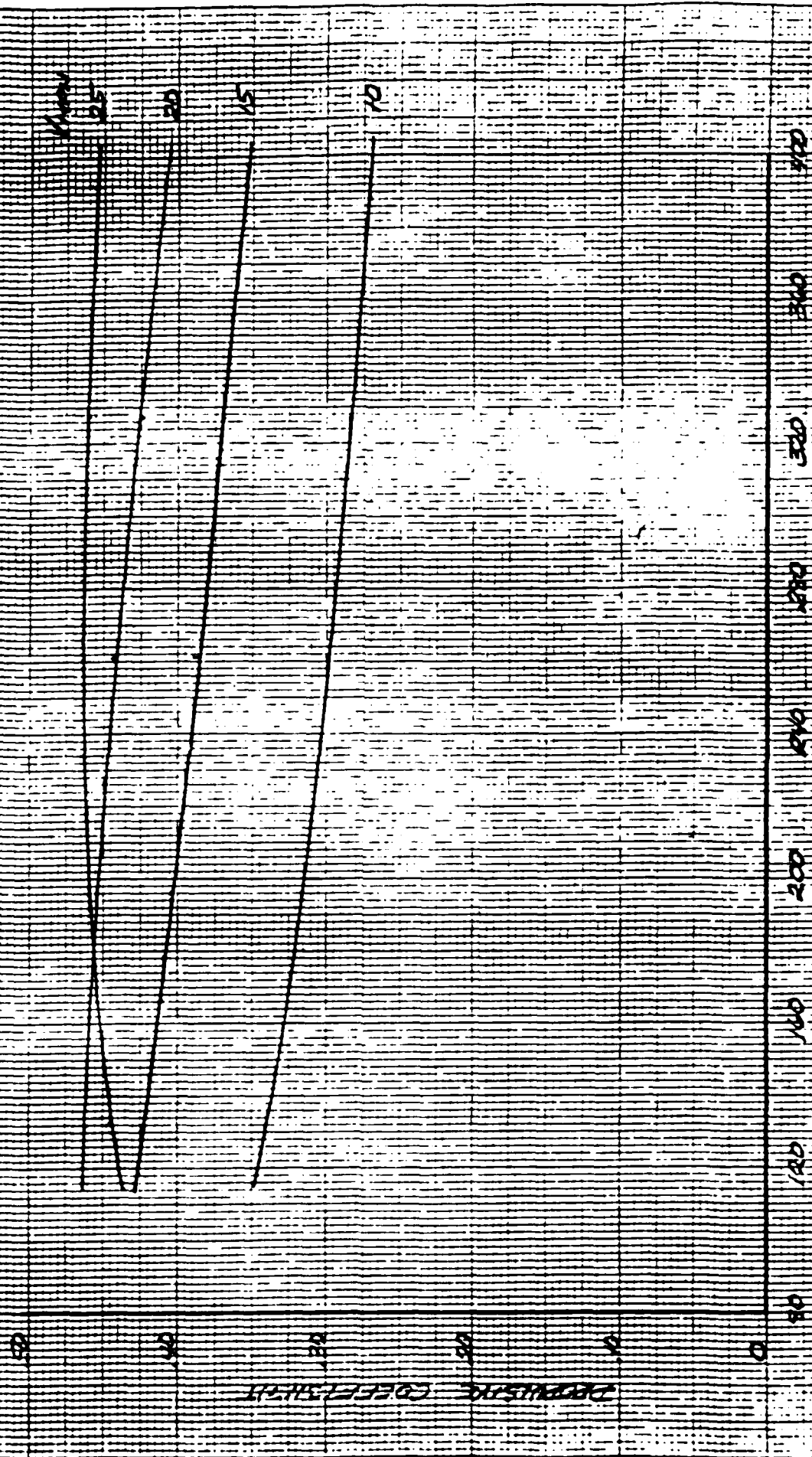
# ESTIMATED PERFORMANCE (Cavitation Limit)

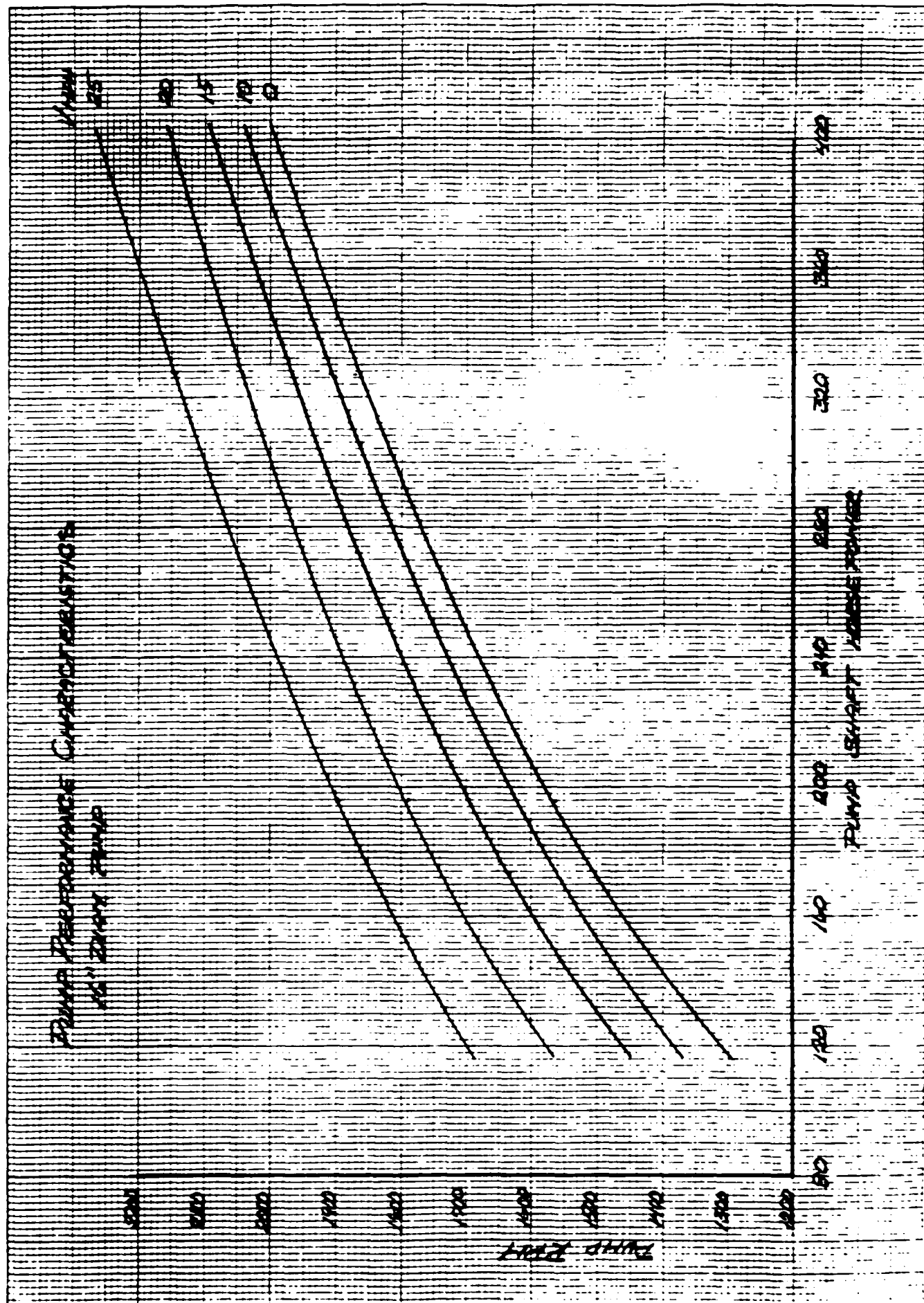
## CALCULATION

| <u>V<sub>mpm</sub></u> | <u>σ</u> | <u>T<sub>10</sub></u> | <u>T<sub>16</sub></u> |
|------------------------|----------|-----------------------|-----------------------|
| 0                      | 1.00     | 2892                  | 3777                  |
|                        | .75      | 3264                  | 4263                  |
| 10                     | 1.00     | 2210                  | 2887                  |
|                        | .75      | 2560                  | 3344                  |
| 15                     | 1.00     | 2012                  | 2628                  |
|                        | .75      | 2375                  | 3102                  |
| 20                     | 1.00     | 1872                  | 2445                  |
|                        | .75      | 2262                  | 2954                  |
| 25                     | 1.00     | 1773                  | 2316                  |
|                        | .75      | 2201                  | 2875                  |



# PUMP PERFORMANCE CHARACTERISTICS 16" DIAM. PUMP





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