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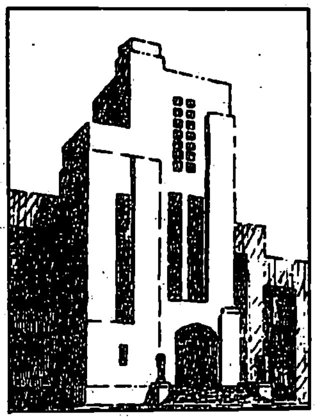
THE DEVELOPMENT AND EVALUATION OF THE
TMB KNOTMETER TYPE 205A

by

Leo F. Fehlner and Thomas Gibbons



RESEARCH AND DEVELOPMENT REPORT

January 1956 Report 1026

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# THE DEVELOPMENT AND EVALUATION OF THE TMB KNOTMETER TYPE 205A

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## ABSTRACT

The design and evaluation of an instrument to measure the speed of a ship relative to the undisturbed water is presented. This device consists of a towed body and associated instrumentation and is known as TMB Knotmeter Type 205A. The knotmeter towed satisfactorily in the "high-speed" basin at speeds up to 30 knots. Although 15 knots was the top speed attained at sea due to limitations on other towing gear, it is not anticipated that difficulty would be encountered in reaching higher speeds. The body was launched and retrieved from the side and stern of the towing vessel with no difficulty.

## INTRODUCTION

As a result of previous sea trials aboard naval surface ships, it became evident that the previous methods of measuring and indicating ship speed were inadequate. A specially designed towed body and its associate electronic equipment, known as the TMB Knotmeter Type 205A, was therefore developed and constructed. This knotmeter was designed to be towed from a ship at speeds up to 30 knots and at depths of approximately 100 feet so that it would tow out of the pressure field of the towing ship. The knotmeter indicates the speed of the ship, in knots, relative to the undisturbed water. Also, it was designed small enough for two men to launch and retrieve at speeds of 3 to 6 knots.

This report presents an account of the design procedure and the results of evaluation tests of the TMB Knotmeter Type 205A. Additional data are provided for installation, maintenance and adjustments of the knotmeter and associated equipment.

## DETAILS OF DESIGN

### BODY

To provide an adequate streamline housing for the pulse generator and magnetic pickup, a body of revolution with a fineness ratio of 5 was selected. A photograph of the body is shown in Figure 1. The body is composed of several sections, consisting of a 2-to-1 ellipsoidal nose, a cylindrical center body and a conical tail section. The housing and its components were made of brass to prevent sea-water corrosion.

### WING

From the results of cable calculations based upon the tables given in Reference 1, it was determined that the knotmeter body would have to produce a total downward force of 900 pounds at 30 knots. The weight of the body and its internal parts were expected to be approximately 100 pounds in water, leaving 800 pounds to be supplied by a depressing wing.

The lift force developed by a wing can be expressed as [2,3]

$$L = \frac{1}{2}\rho U^2 S_W C_L \left(1 - \frac{R^2}{(b/2)^2}\right) \qquad [1]$$

where

$\rho$ is the fluid mass density,

$U$ is the towing velocity,

$S_W$ is the projected area of the wing,

$C_L$ is the lift coefficient,

[2,3] References are listed on page 12

b  is the span of the wing as shown in Figure 2,

R  is the effective radius of the body (equal to D/2), and

$\left[1 - \frac{R^2}{(b/2)^2}\right]$ is a factor which approximately accounts for the wing-body interference.

By substituting in Equation [1] for the wing span in terms of the wing-aspect ratio, it follows that the wing area is

$$S_W = \frac{L}{\frac{1}{2}\rho U^2 C_L} + \frac{4R^2}{a} \qquad [2]$$

where

a  is the wing aspect ratio, $\frac{b^2}{S_W}$ .

If the values,

$C_L$ = 0.4,

U = 50.7 feet/second (30 knots),

R = 0.25 feet,

a = 4,

L = 800 pounds, and

$\rho$ = 2 slugs/cubic foot

are substituted in Equation [2] the area of the wing, $S_W$, is 0.84 square feet.

The lift coefficient of a wing of finite aspect ratio can be expressed according to lifting-line theory[2] as

$$C_L = \frac{a}{a+2K} 2\Pi K \sin \alpha \qquad [3]$$

where

$\alpha$ is the angle of attack of the wing,

K is correction factor to the section lift curve slope of $2\Pi$ which accounts for the section thickness (K = 0.9).

Assuming a lift coefficient of 0.4, an aspect ratio of 4, and that for small angles $\sin \alpha$ is equal to $\alpha$ in radians, Equation [3] gives the required wing angle of attack as 5.8 degrees.

TAIL SURFACES

Using the approximate method described in Reference 2, the hydrodynamic moment produced by the tail surfaces can be written as

$$M_T = S_T l_T \tfrac{1}{2}\rho U^2 \frac{a_T}{a_T + 2K} 2\Pi K \sin \alpha \qquad [4]$$

The Munk or ideal moment[4] produced by the body is

$$M_B = \forall (K_2 - K_1) \tfrac{1}{2}\rho U^2 \sin 2\alpha \qquad [5]$$

where

$M_T$ is the moment produced by tail surfaces,

$M_B$ is the moment produced by the body,

$S_T$ is the total area of tail surfaces,

$\ell_T$ is the distance from center of pressure of tail surface to center-of-pressure of body and tail surfaces combined,

$a_T$ is the aspect ratio of tail surfaces based on total area and equal to $\frac{b^2}{S_T}$,

$(K_2 - K_1)$ is the virtual mass factor, and

$\mathcal{V}$ is the volume of body.

Equating Equations [4] and [5] for equilibrium and assuming for small angles sin $\alpha$ is equal to $\alpha$ in radians, the total tail area, $S_T$, for the case where the tail surfaces are 45 degrees with respect to the body axis is

$$S_T = \frac{(K_2 - K_1)\mathcal{V}}{1.4\ell_T\pi \frac{a_T K}{a_T + 2K}} \qquad [6]$$

where 1.4 is a factor to allow for the 45-degree orientation of the tail surfaces.[2] For an ellipsoid of fineness ratio 5, the virtual-mass factor $(K_2 - K_1)$ equals 0.836.[5]

Assuming

$\ell_T$ = 0.75 feet

$\mathcal{V}$ = 0.296 cubic feet

$a_T$ = 4.0

then from Equation [6] the required tail area, $S_T$, is 0.12 square feet.

No correction was made to the lift to account for the sweep back of the tail surfaces. The tail surfaces were swept back to protect the impeller when the body is on the deck and to allow sea weed to slide off the surfaces. There was no correction made to the Munk or ideal moment to account for viscous effects as shown in Reference 7.

### TOW POINT

To facilitate handling of the body in air and to orient the housing advantageously for its entry into the water, the body should hang horizontally from its tow cable in the air. The center of buoyancy was selected as the towpoint and the body ballasted so that its center of gravity was located below the towpoint and on a vertical line containing the towpoint and quarter chord of the wing. Experience obtained in towing previous towed housings indicates that it is necessary to provide a rigid towstaff to avoid chafing of the cable or cable fairing at the intersection of cable and body[2]. The towstaff was extended out of the body approximately 6 inches when vertical, as shown in Figure 1. For speeds up to 30 knots the towstaff was given freedom to pivot forward about 15 degrees.

### IMPELLER

A three-bladed impeller was designed, which rotates at approximately 66⅔ revolutions per minute per knot. This impeller drives the transducer which is used to generate pulses. The blades of the impeller, as shown in Figure 2, are swept back 15 degrees to prevent sea weed from gathering on them.

## INSTRUMENTATION

### TRANSDUCER

The transducer consists of a brass disk, with 90 equally-spaced iron slugs around it. The impeller wheel drives the disk past an electromagnetic pickup and pulses are generated and carried up the tow cable to the indicating system.

## SPEED INDICATOR

From the electromagnetic pickup, the speed indicating system counts and displays the pulses on a Berkley Counter. These pulses are produced at a rate of 200 per second per knot. Therefore, counting for 1/2 second, a speed of 10 knots produces 1000 pulses on the Berkley Counters and with proper placement of the decimal, the resulting reading is 10 knots. This calibration is the same over the speed range since the impeller RPM varies linearly with speed.

# EVALUATION TESTS

## BASIN TESTS

The knotmeter towed satisfactorily at speeds up to 30 knots in the "high-speed" basin. The instrumentation was calibrated with the TMB high-speed towing carriage. The variation of the cable tension at the body with speed is presented in Figure 3.

## SEA TRIALS

The TMB knotmeter was used sucessfully on sea trials. Over a period of approximately four months at sea, minor troubles were discovered and corrected such as, excessive cable vibration at the towstaff, bearing failure and corrosion of tow cable. A variation in the indicated readings due to pitching and rolling of the ship was noted. This may be minimized by increasing the counting period and indicating the average speed over a longer time interval. Although, 15 knots was the top speed attained at sea due to limitations on other towing gear, it is not anticipated that difficulty would be encountered in reaching higher speeds. The body was launched and retrieved from the side and stern of the towing vessel with no difficulty.

# ACKNOWLEDGMENTS

The design and development of the electronic instrumentation was carried out by Mr. J. F. Hunt with the assistance of Mr. G. N. Metsel.

# APPENDIX

## Knotmeter Installation, Maintenance and Adjustment

From the results of previous sea trials, it appears that the location of the knotmeter launching site on the deck of the ship need not be restricted. It is recommended, however, that the location of the launching site be such that the ship motion is a minimum. The knotmeter cable used in all sea trials was a 1-H-O, 0.185-inch diameter stainless steel cable, number 18 AWG conductor, Kel-F insulation, manufactured by American Steel and Wire Company.

Figure 4, presents the variation of the towing depth of the knotmeter as a function of speed and scope of tow cable. Greater towing depths may be obtained by installing a cable fairing on the tow cable. These towing depths may be calculated using the procedure of Reference 1.

The special instructions for connecting the tow cable to the towstaff are given in Figure 5 which also shows the assembly of transducer, magnetic pickup, impeller, and bearings. The modification made to the towstaff to reduce the effect of vibration, is also shown in Figure 5. This consists of the addition of a six-inch section of rubber fairing whose shape is given in Reference 6. This rubber fairing substantially reduces the effect of cable vibrations at the towstaff and prolongs the life of the tow cable.

The instrumentation is housed in a cabinet, as shown in Figure 6. This cabinet may be located in some convenient place and connected to a standard 115 volts 60 cps a-c source. The lead from the cabinet is plugged into the connector from the tow cable and the operation is automatic when the power is turned on. The following figures show the electronic instrumentation; Figure 7-block diagram, Figure 8-circuit diagram, Figure 9-power supply. A parts list of the instrumentation and power supply are included. Additional information on the design and construction of the electronic instrumentation may be obtained from the preliminary report by Mr. H.B.O. Davis, entitled "The Circuitry of An Accurate High Resolution Knotmeter TMB Type 205", October 1954.

TABLE 1

Parts List for TMB Knotmeter Type 205A Instrumentation

| | | | | | |
|---|---|---|---|---|---|
| R1 | 3M | R31 | 100 K | R61 | 4.7K |
| R2 | 150 Ohm | R32 | 24 K | R62 | 20 M |
| R3 | 470 K | R33 | 24 K | R63 | 47 K |
| R4 | 27 K | R34 | 33 K | R64 | 200 K |
| R5 | 180 K | R35 | 50 K Precision | R65 | 47 K |
| R6 | 150 Ohm | R36 | 50 K Potentiometer | R66 | 47 K |
| R7 | 15 K | R37 | 50 K Precision | R67 | 270 K |
| R8 | .5M | R38 | 22 K | R68 | 270 K |
| R9 | 150 Ohm | R39 | 22 K | R69 | 100 K |
| R10 | 5 K | R40 | 2 M | R70 | 12 K |
| R11 | 27 K | R41 | 1.8 K | R71 | 100 K |
| R12 | 47 K | R42 | 18 K | R72 | 1 M |
| R13 | 150 Ohm | R43 | 210K | R73 | 220 K |
| R14 | 150 Ohm | R44 | 270 K | R74 | 10 K |
| R14 | .5M | R45 | 390 K | R75 | .5 M |
| R16 | 2 M | R46 | 50 K Potentiometer | R76 | 47 K |
| R17 | 22 K | R47 | 47 K | R77 | 100 K |
| R18 | 22 K | R48 | 47 K | R78 | 10 K Pot. |
| R19 | 1.8 K | R49 | 4.7 K | R79 | 500 Ohm |
| R20 | 18 K | R50 | 390 K | R80 | 220 K |
| R21 | 270 K | R51 | 50 K Potentiometer | R81 | 120 K |
| R22 | 270 K | R52 | 5M | R82 | 27 K |
| R23 | 100 K | R53 | 47 K | R83 | 10 K |
| R24 | 100 K | R54 | 47 K | R84 | 150 Ohm 10 W |
| R25 | 20 K | R55 | 4.7 K | C2 | .1 µf |
| R26 | 2.5 K 10W | R56 | 50 K Potentiometer | C3 | 20 MFD |
| R27 | 10 K | R57 | 390 K | C4 | .01 µf |
| R28 | 100 K | R58 | 10 M | C5 | 40 µµf |
| R29 | 51 K | R59 | 47 K | C6 | .01 µf |
| R30 | .5 M | R60 | 47 K | C7 | .5 µf |

TABLE 2 (Cont.)

| | |
|---|---|
| C8 | 100 µµf |
| C9 | 100 µµf |
| C10 | 20 MFD |
| C11 | .01 µf |
| C12 | .1 µf |
| C13 | 8 µf |
| C14 | Picked to set Oscillator Frequency |
| C15 | .05 µf Silver Mica |
| C16 | .1 µf |
| C17 | .1 µf |
| C18 | .01 µf |
| C19 | 40 µµf |
| C20 | 40 µµf |
| C21 | 40 µµf |
| C22 | .0045 µf |
| C23 | 40 µµf |
| C24 | .03 µf |
| C25 | .15 µf |
| C26 | 150 µf |
| C27 | 50 µf |
| C28 | 50 µf |
| C29 | 01 µf |
| C30 | 100 µµf |
| C31 | 25 µf |
| C32 | .01 µf |
| C33 | .01 µf |
| V-1 | 5814 |
| V-2 | 5814 |
| V-3 | 5814 |
| V-4 | 5814 |
| V-5 | 5814 |
| V-6 | 5814 |
| V-7 | 5963 |
| V-8 | 5727 |
| V-9 | $\frac{1}{2}$5814 |
| V-10 | 6AU6 |
| V-11 | 6AU6 |
| V-12 | 5814 |
| V-13 | 5963 |
| V-14 | $\frac{1}{2}$5814 |
| **Crystal Diode** | |
| D-1 | IN63 |
| D-2 | IN63 |
| D-3 | IN63 |
| SI-DPST | |
| S2-DPST | |
| **Connectors** | |
| V-1 | AN3102-16S-5P |
| V-2 | AN3105-20-16P |
| V-3 | Pinconnector for D.C.V. $B_1$ |
| V-4 | 8 Pinconnector for D.C.V. $B_1$ |
| V-5 | 8 Pinconnector for D.C.V. $B_1$ |
| V-6 | 8 Pinconnector for D.C.V. $B_1$ |
| TP-1 | Banana Jacks |
| TP-2 | Banana Jacks |
| TP-3 | Banana Jacks |
| TP-4 | Banana Jacks |
| TP-5 | Banana Jacks |
| TP-6 | Banana Jacks |
| I-1 | Even Pilot Light NEON |
| H-1 | 6W 110 V |
| H-2 | 6W 110 V |
| H-3 | 6W 110 V |

# TABLE 2

## Knotmeter Type 205A Power Supply

### Resistors

| | | |
|---|---|---|
| R1 | 12 K | 10 Watts |
| R2 | 100 K | 1 Watt |
| R3 | 47 K | 1 Watt |
| R4 | 180 K | 1 Watt |
| R5 | 82 K | 1 Watt |
| R6 | 500 K | 1 Watt |
| R7 | 10 K | 1 Watt |
| R8 | 40 K | 1 Watt |
| R9 | 10 K | 10 Watts |
| R10 | 1 Meg. | 1 Watt |
| R11 | 1 Meg. | 1 Watt |
| R12 | 100 K | 1 Watt |
| R13 | 100 K | 1 Watt |

### Capacitors

| | | |
|---|---|---|
| C1 | 4 MFD | 600 V.D.C. |
| C2 | 4 MFD | 600 V.D.C. |
| C3 | 4 MFD | 600 V.D.C. |
| C4 | .1 MFD | 400 V.D.C. |
| C5 | 8 MFD | 450 V.D.C. |
| C6 | 8 MFD | 450 V.D.C. |

### Transformers

| | | |
|---|---|---|
| T1 | Chicago | PV 200 |
| R2 | 21F08 fil. | 1 Amp. |

### Inductors

| | | |
|---|---|---|
| L1 | 8 Henry | 150 Ma. |
| L2 | 8 Henry | 150 Ma. |
| L3 | 8 Henry | 40 Ma. |

### Valves

| | |
|---|---|
| V1 | 5V4G |
| V2 | 6Y6G |
| V3 | 6AU6 |
| V4 | OA2 |
| V5 | OA2 |
| V6 | 6X5 |

### Miscellaneous

| | |
|---|---|
| SW1 | S.P.S.T. |
| Fuse | 3 Amp. |

## REFERENCES

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7. Johnson, J. L. "The Static Stability Derivatives of a Series of Related Bodies of Revolution", TMB CONFIDENTIAL Report C-383, March 1951.

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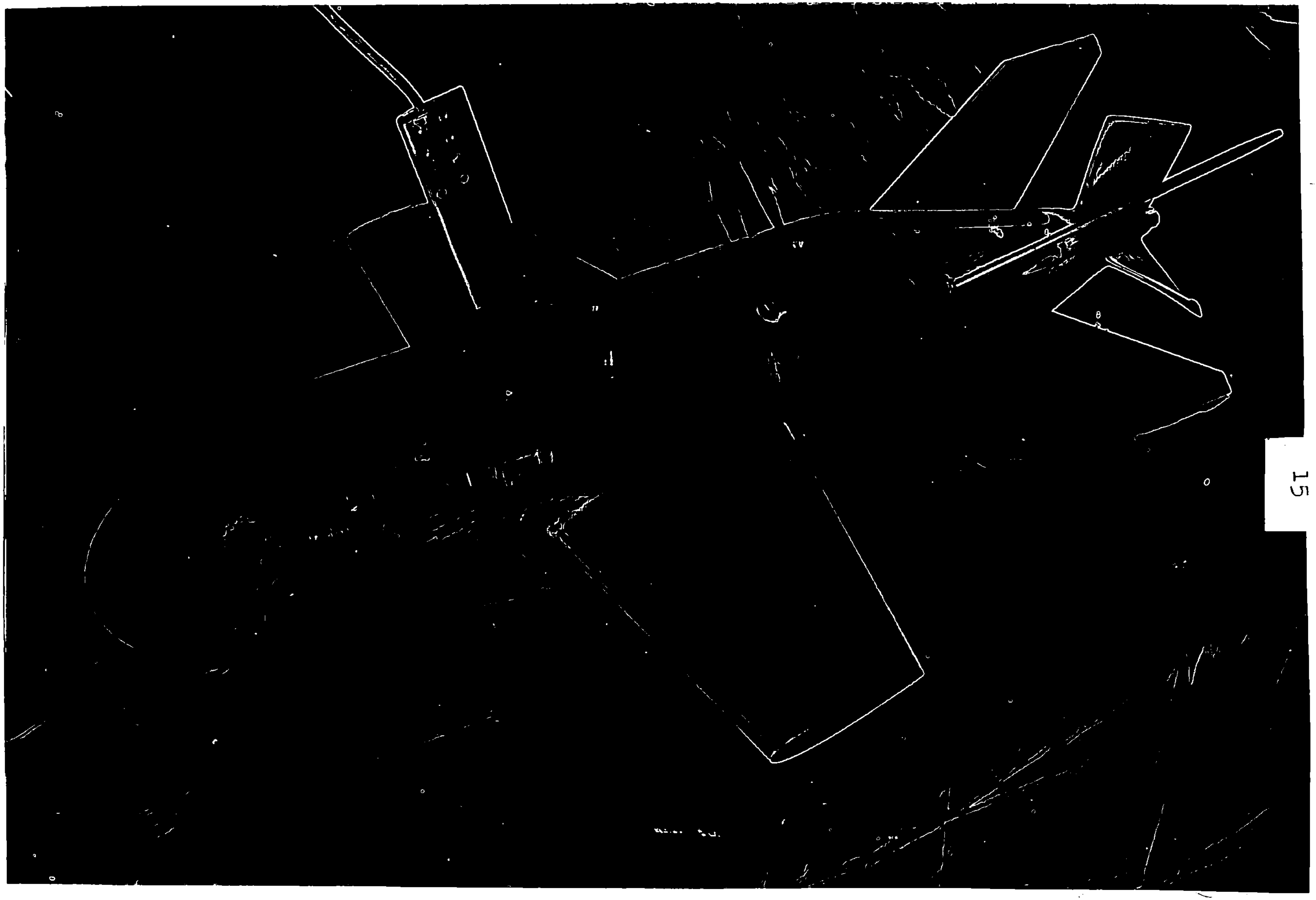



NP21-59913 Figure 1-Towed body for the TMB Knotmeter Type 205 A 2-21-55

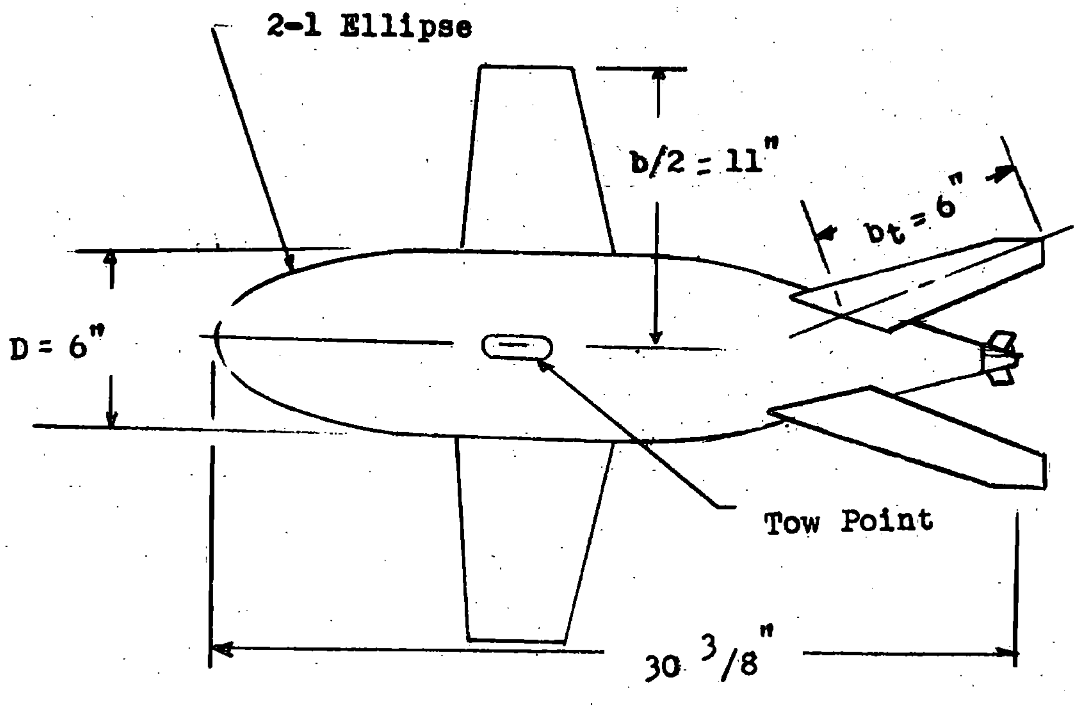


Figure 2- Schematic Diagram of the Body for the TMB Knotmeter Type 205A

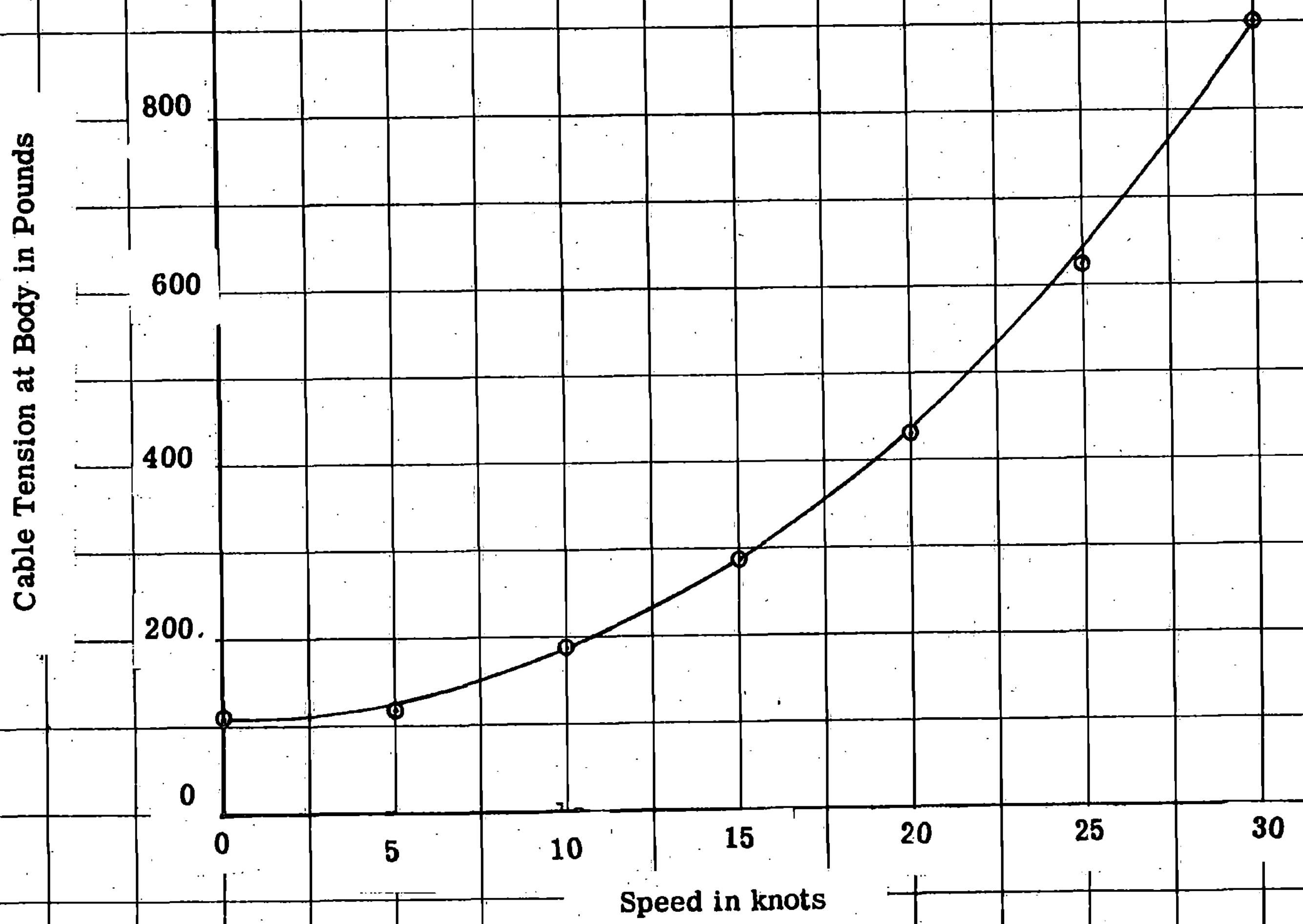


Figure 3- Cable Tension at the Body as a Function of Towing Speed

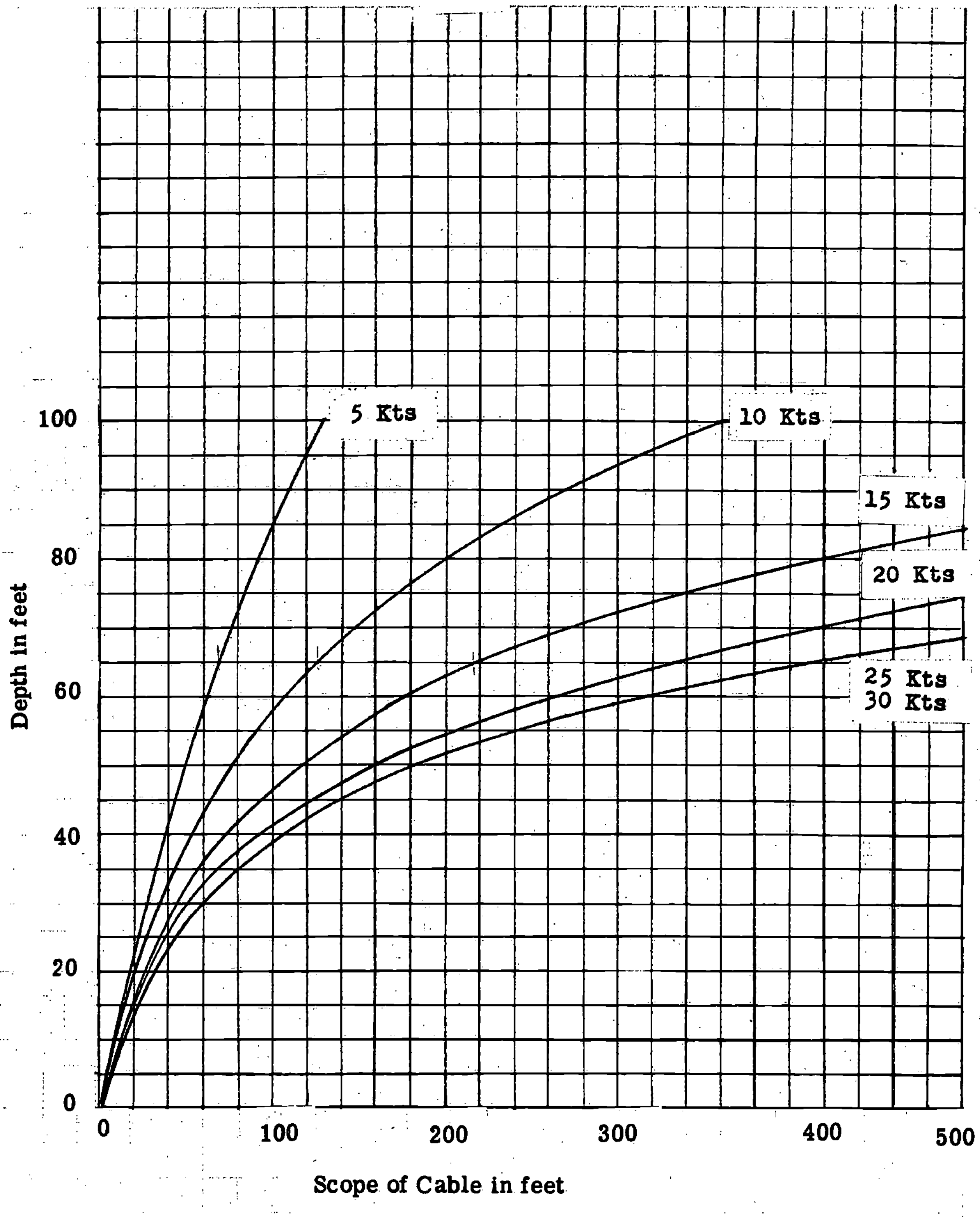


**Figure 4-Depth of TMB Knotmeter as a Function of Speed and Scope of Cable**

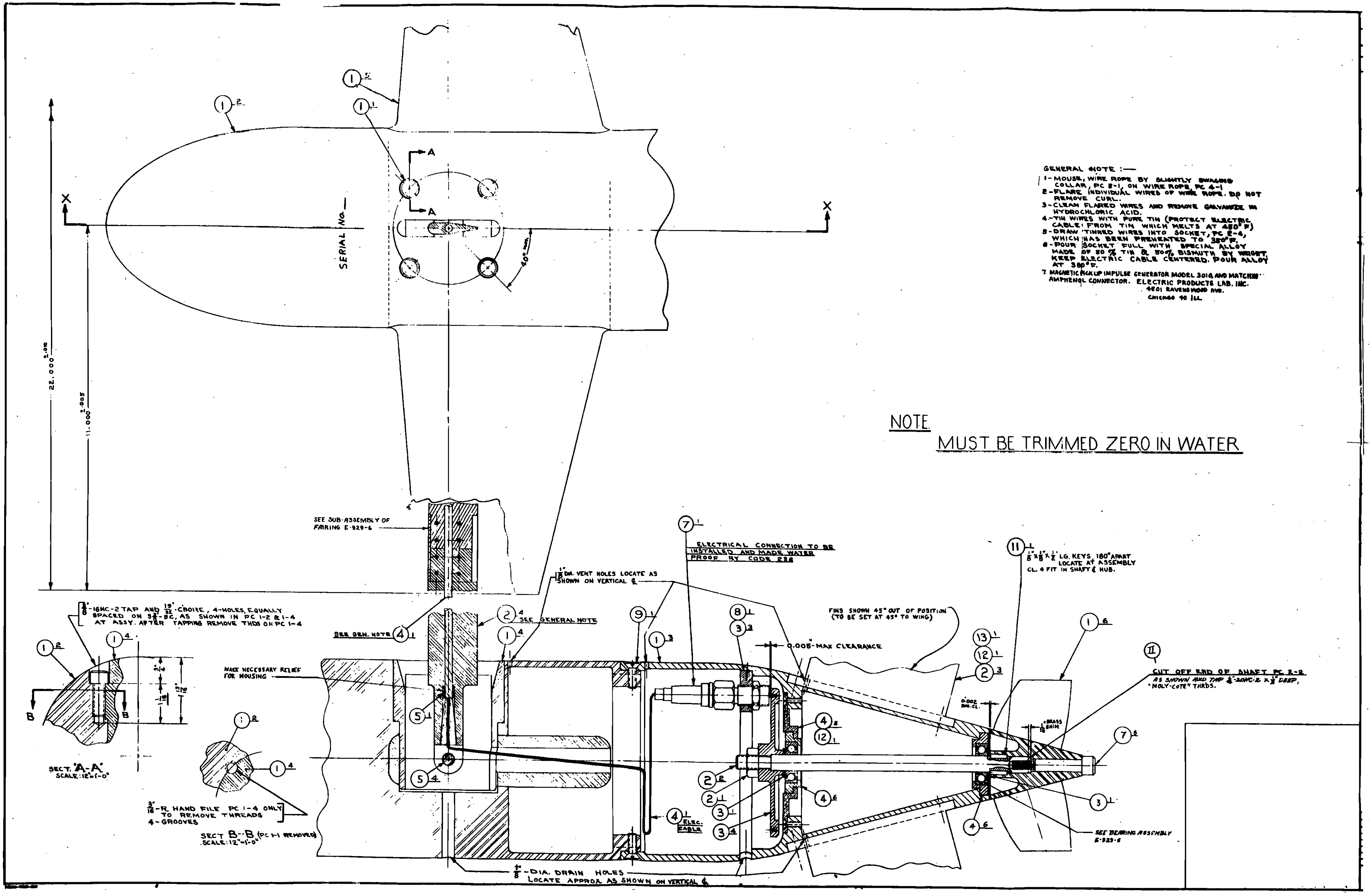


**Figure 5—Assembly Drawing of Towed Body**

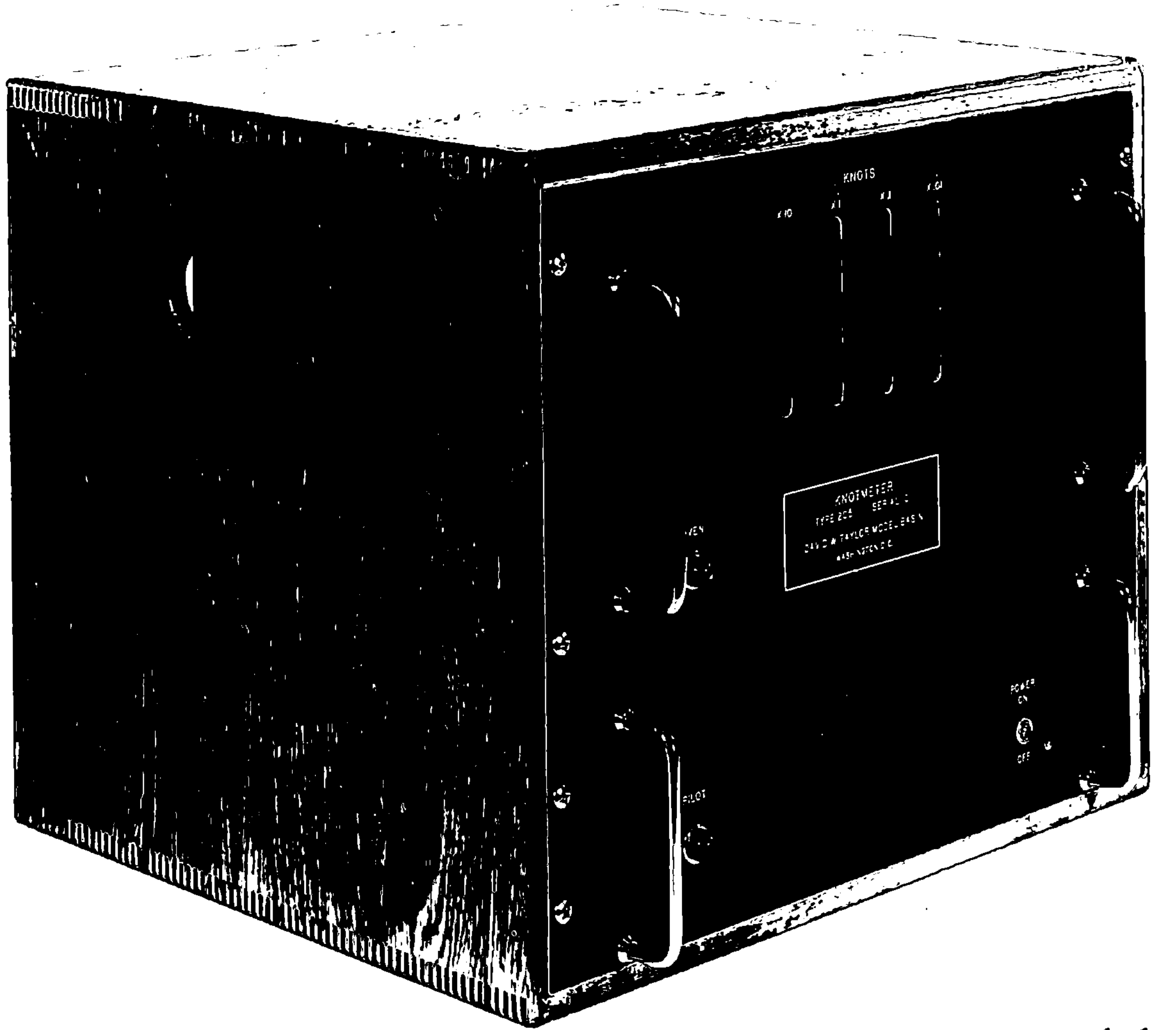


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**Figure 6 - TMB Knotmeter Type 205A Instrumentation Cabinet**

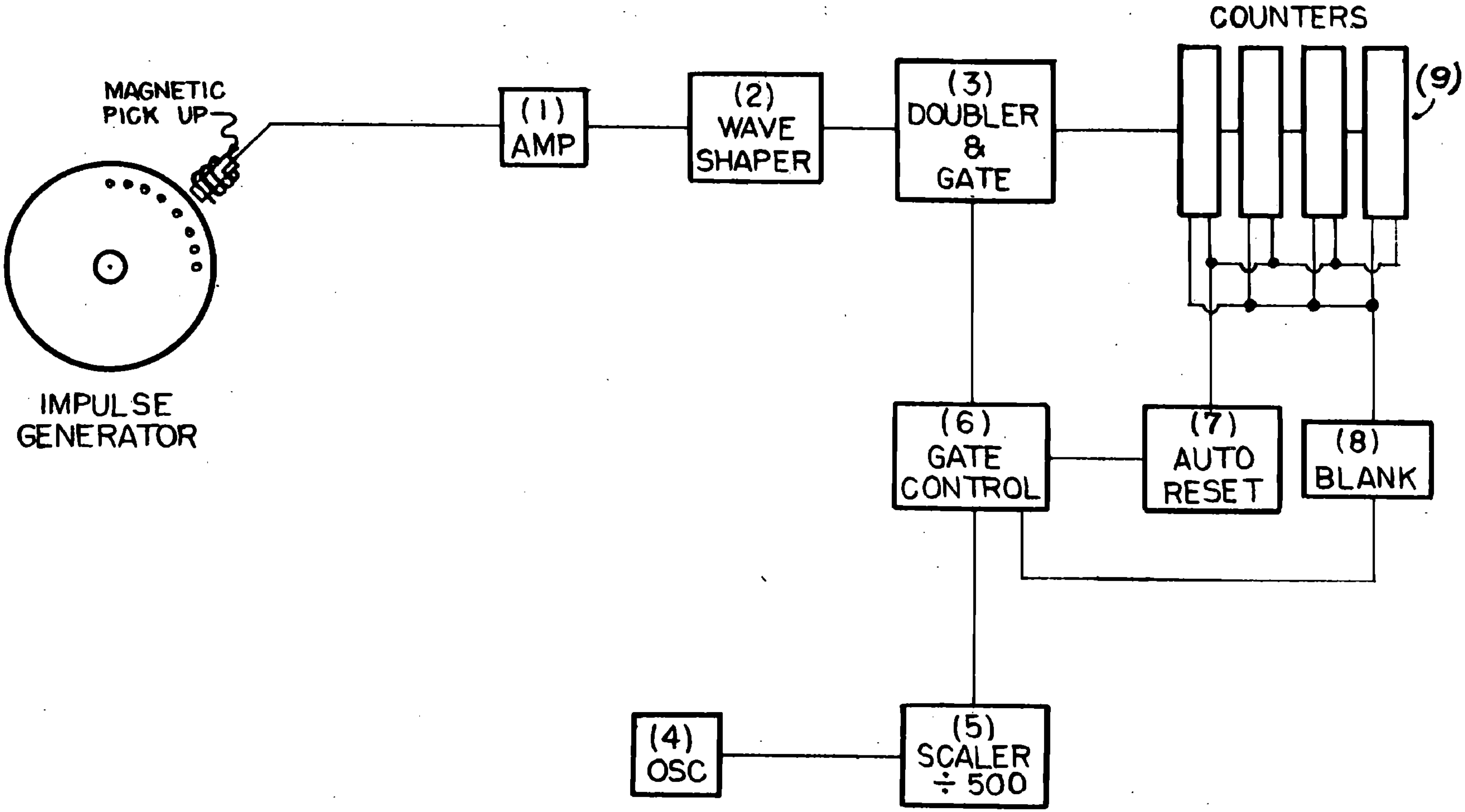


**Figure 7- Block Diagram TMB Knotmeter Type 205A**

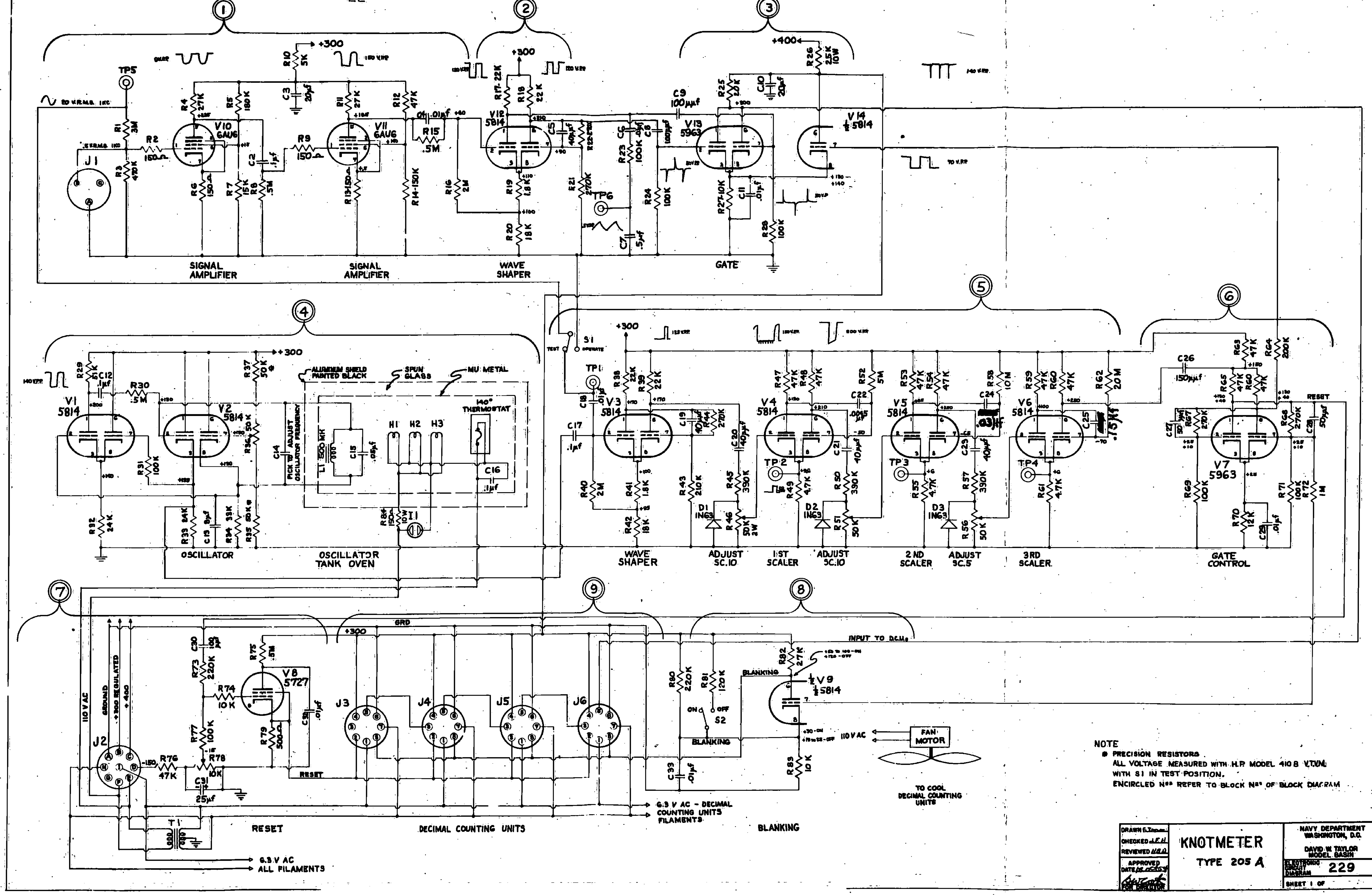


**Figure 8-Circuit Diagram TMB Knotmeter Type 205A**

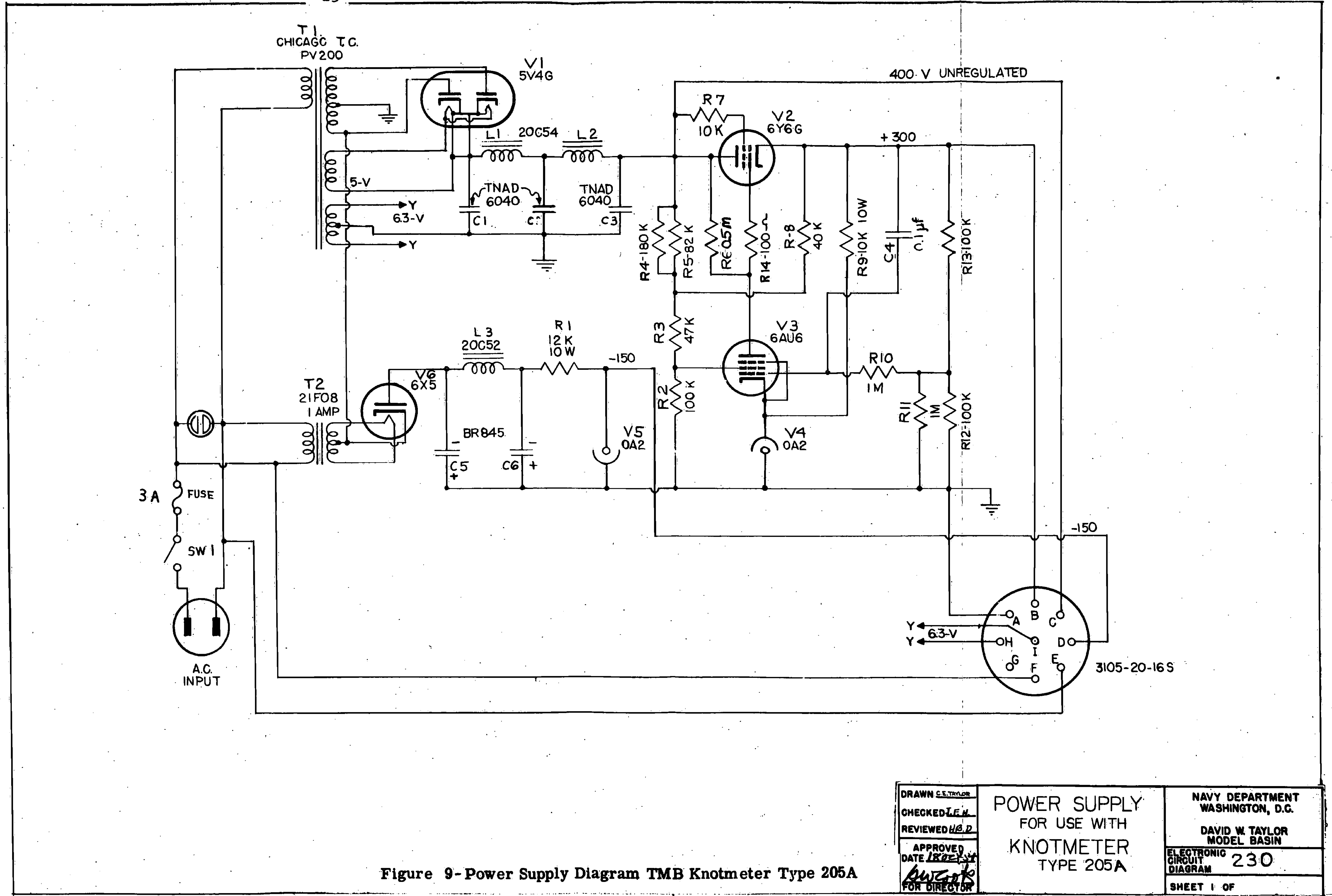


**Figure 9- Power Supply Diagram TMB Knotmeter Type 205A**