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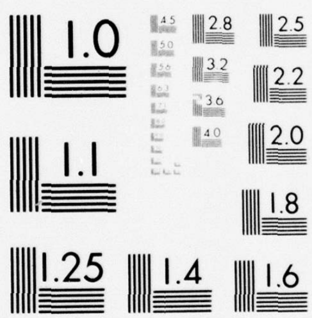

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TECHNICAL MEMO

NAVAL ARCHITECTURE - PRELIMINARY HULL DESIGN ANALYSIS (U)

CONFORMAL/PLANAR ARRAY SONAR PROJECT

30 December 1965 690425-0260

Contract NObsr 93022
Project Serial Number SS-048-00
Task 8189
(GE Requisition Number EH-88157)

Prepared by
General Electric Company
Heavy Military Electronics Division
Syracuse, N.Y.

Prepared for
Navy Department Bureau of Ships
U.S. Navy Electronics Laboratory
San Diego, California

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REPORT

NAVAL ARCHITECTURE

CONFORMAL/PLANAR ARRAY SONAR SYSTEM [redacted]

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(11) 30 Dec[redacted]65

(15) Contract NObsr-93022
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(12) 65p.

(9) Technical memo.

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General Electric Company
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U.S. Navy Electronics Laboratory
San Diego, California

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NAVAL ARCHITECTURE

CONFORMAL/PLANAR ARRAY SONAR SYSTEM

Approved by:

General Electric Company

R. A. Rourke, Responsible Engineer

W. L. Dunkle, Project Manager

NEL, Code 2110

M. M. Baldwin, Project Technical Director

CHANGE SHEET

CHANGE NUMBER	PAGE NUMBER	EFFECTIVE DATE

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Concluded)

* Davidson Laboratory Photo Identification Numbers
** Number refers to Davidson Laboratory Test

LIST OF TABLES

ABSTRACT

This report presents the results of ship model tests conducted on a destroyer type hull form which was fitted with a number of array housings, each suitable for accommodating different sizes of horizontally oriented conformal/planar array sonar transducers. The basic hull form was developed from ship characteristics furnished by the Bureau of Ships. These tests were limited to obtaining resistance test data, flow test photographs and wave profile photographs; since these were considered sufficient to provide parametric naval architectural inputs to a trade-off analysis of hydrodynamic versus sonar performance. To aid in evaluating the hydrodynamic performance of these array housings, tests were also conducted for the basic hull without sonar appendages and for the basic hull with the dome for the AN/SQS-26 sonar transducer appended. All array housings tested offered considerable improvement in total ship resistance over the AN/SQS-26 dome throughout the low and moderate speed ranges. Relative sensitivities of changes in array dimensions upon total ship resistance are included in this report. Lines plans of the basic hull form and of the two array housings selected from the results of the preliminary trade-off analysis of hydrodynamic versus sonar performance have been furnished the David Taylor Model Basin (DTMB) for further ship model investigations including resistance, maneuvering, sea-keeping, directional stability, local flow behavior and cavitation inception.

SECTION I

INTRODUCTION

The naval architectural task assignment for phase I of contract NObsr 93022 was to define a destroyer type hull form which would comply with the "Hull Form Information" furnished by the Bureau of Ships, and which would properly incorporate the General Electric Company's conformal/planar array sonar transducer housing design.

The basic ship characteristics and associated information supplied by the Bureau of Ships are as follows:

A. HULL FORM INFORMATION

All information applies to the molded hull without domes, array housings or fairings.

Displacement (molded)	5400 tons
LWL	480 feet
KM	24.5 feet to 25.5 feet
C_B	0.45 to 0.49
C_X	0.775 to 0.845

Notes:

1) Trial speed 34 knots; endurance speed 25 knots.
2) No domes or array fairings to extend more than 10 feet below the bottom of the keel.

B. RELATED NAVAL ARCHITECTURAL CONSIDERATIONS

In arriving at the optimum size, shape, and location for the sonar array(s), consideration shall be given to the following features which influence the design of the ship:

1) Weight, space, manning, electric power, cooling, and other service requirements of the sonar system.
2) The sonar environment including:
   a) Machinery and propeller noise
   b) Flow generated noise
      - Cavitation
      - Turbulent boundary layer noise
   c) Transmission interferences
      - Cavitation
      - Quenching
      - Bubble sweep down

3) The influence of hull/array shape on

   a) Ship powering
   b) Ship maneuvering
   c) Ship motion in a seaway

4) Ship structure including

   a) Slamming
   b) Array deflection

5) Construction and maintenance including

   a) Access and maintenance of the array while at sea
   b) Dimensional tolerances and array alignment
   c) Hull surface preservation

6) Ship operating problems including

   a) Drydocking
   b) Anchoring, berthing, and mooring

The conformal approach was defined by Navy representatives as follows: "An array orientation which results from a technical trade-off between sonar and hydrodynamic performance to optimize both insofar as possible. The transducer does not necessarily have to conform to the hull contours."

Preliminary design effort conducted by the General Electric Company prior to the commencement of phase I of contract NObsr 93022 had indicated that a horizontal transducer array approximately 7 feet wide by 70 feet long, housed in a rubber dome with a radius of curvature to permit dome clearance of approximately 1.5 feet below the array at the ship's centerline, appeared the most promising. This horizontal array was to be mounted immediately under the keel, in a location under the bow of the ship such that the entire array housing was as far forward as practicable.

The development of the basic destroyer type hull form was subcontracted to Gibbs and Cox, Incorporated, Naval Architects and Marine Engineers, New York, New York. In order to aid the General Electric Company in selecting the proper dimensions for the horizontal keel-mounted transducer which would optimize both sonar and ship's hydrodynamic performance, it was considered necessary to conduct a series of ship model tests to obtain parametric information on the effects of predicted ship performance whenever the dimensions of the sonar transducer and its associated array housing were varied in length or width, and its vertical location varied with respect to the ship's keel or base line (i.e., depth of array housing with reference to the ship's base line).

Arrangements were made by Gibbs and Cox, Incorporated to have the required ship model tests conducted at the Davidson Laboratory, Stevens Institute of Technology, Hoboken, New Jersey. From preliminary discussions with David Taylor Model Basin (DTMB) personnel, it was determined that resistance test data, flow test photographs, and wave profile photographs for each of the array housing designs under consideration would provide sufficient parametric information for the preliminary naval architectural inputs to the trade-off analyses of hydrodynamic versus sonar performance. Upon completion of these preliminary hydrodynamic tests at Stevens Institute of Technology, the basic hull form and selected array housing designs were to be modified as determined from test results, and were then to be furnished to the David Taylor Model Basin for additional testing. This facility has the capability to conduct tests using larger models than does Stevens Institute of Technology, and thus can obtain more refined resistance and powering data. In addition, the other required ship model tests (such as maneuvering, directional stability, sea keeping, rolling, and circulating water channel flow tests) would be conducted at the David Taylor Model Basin only on the hull form and the array housing designs which were selected as a result of the preliminary trade-off analyses of hydrodynamic versus sonar performance.

SECTION II
PROCEDURE

Gibbs and Cox, Incorporated developed a basic hull form which complies with the "Hull Form Information" and which incorporates those applicable features pertinent to the basic hull form envelope listed in the "Related Naval Architectural Considerations" previously enumerated. This basic hull form is described by Figure 1. The lines were developed using as a guideline the lines of a recent large destroyer. The particulars of this new ship are as follows:

Length overall	505 feet - 0 inch
Length between perpendiculars	480 feet - 0 inch
Beam at design waterline, amidships	52 feet - 2 inches
Depth amidship	30 feet - 9 inches
Design waterline	16 feet - 0 inch
Displacement, molded	5,380 tons
Midship coefficient	0.81
Block coefficient	0.47
Prismatic coefficient	0.58
KM without array housing	25.9 feet

A 1:80 scale wooden model, approximately 6 feet long, was constructed so that its forward section below the load waterline was removable. This permitted installing a number of different bow and associated array housing designs utilizing the same basic model, thus minimizing the cost of obtaining the required preliminary parametric hydrodynamic performance results. This model was a bare hull only, without normal appendages such as bilge keels, shafts, struts and rudders; since comparative rather than absolute values were required.

Array housings were developed to accommodate both a wide range of transducer sizes and to provide for variances in the vertical location of the transducer array with respect to the ship's base line (or keel line) reference axis. Table I denotes the salient features of each of the array housings tested.

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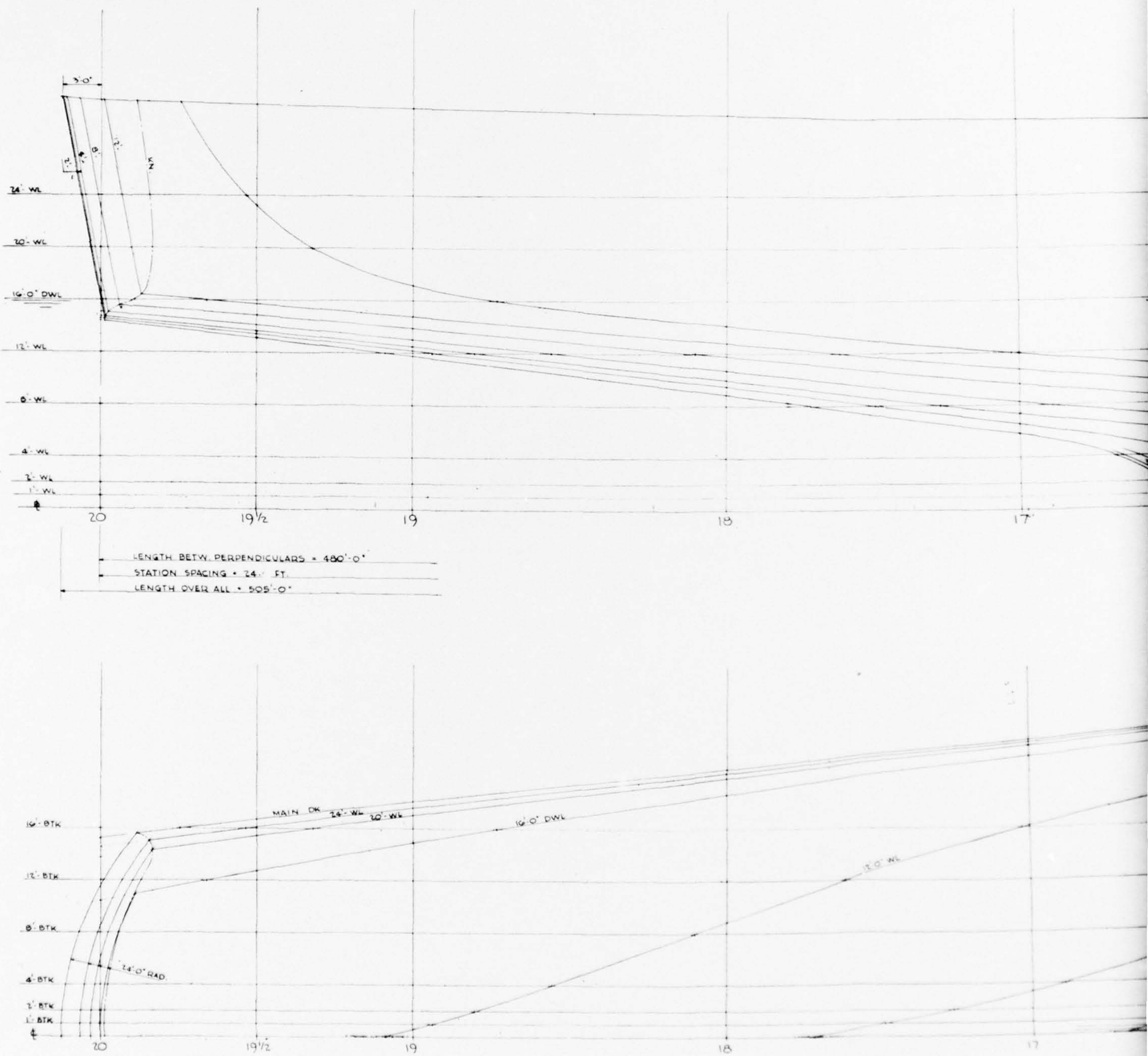

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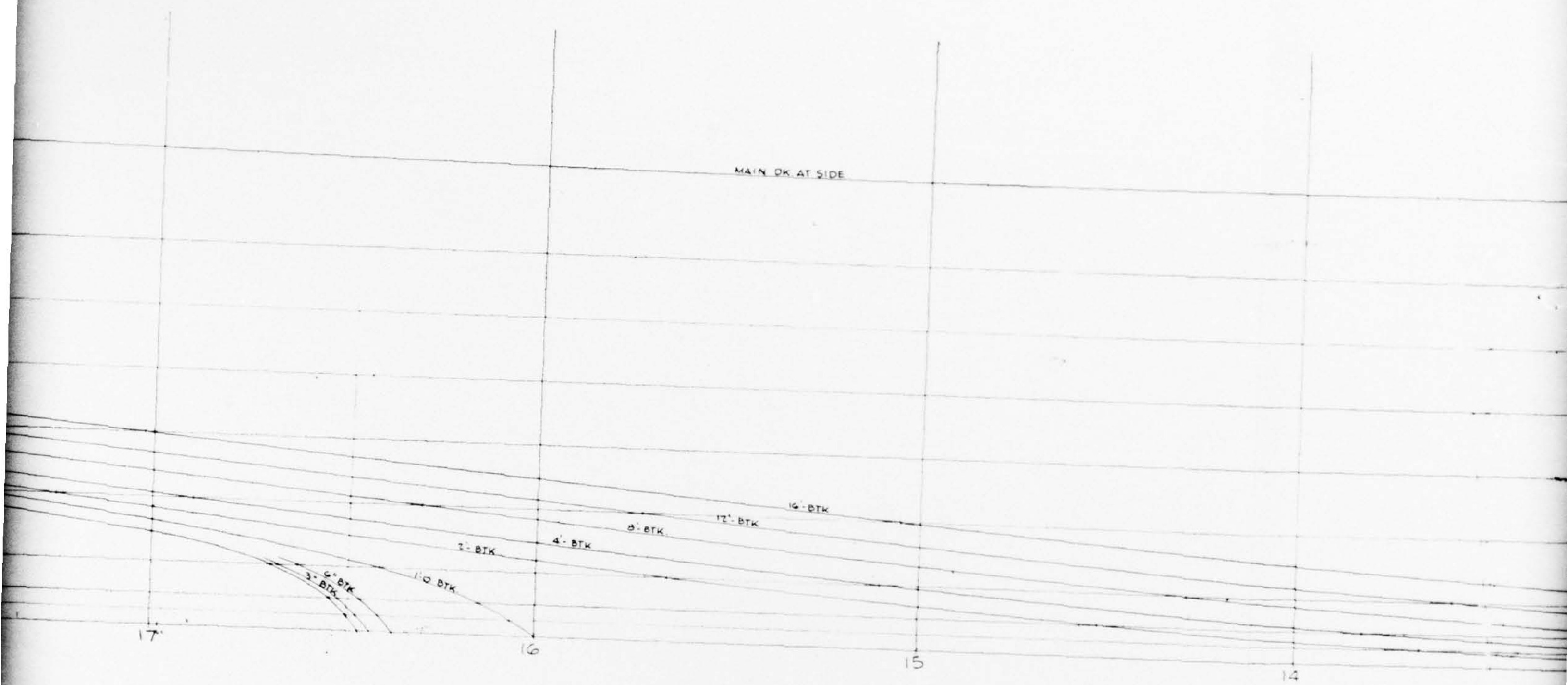

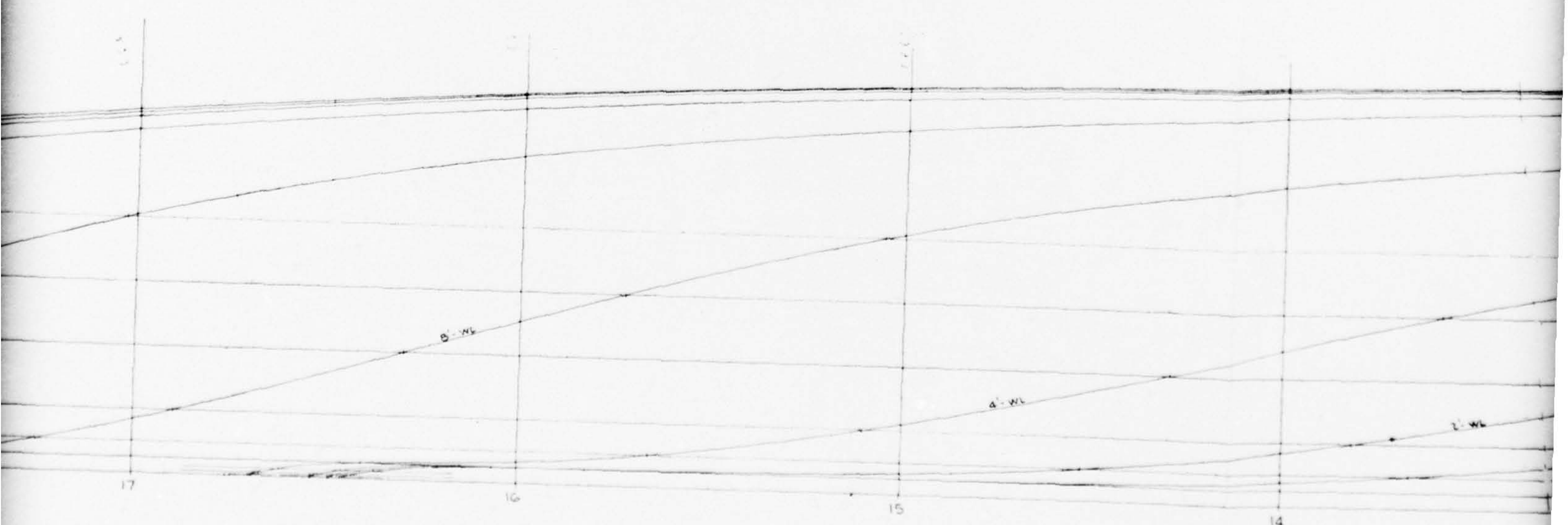

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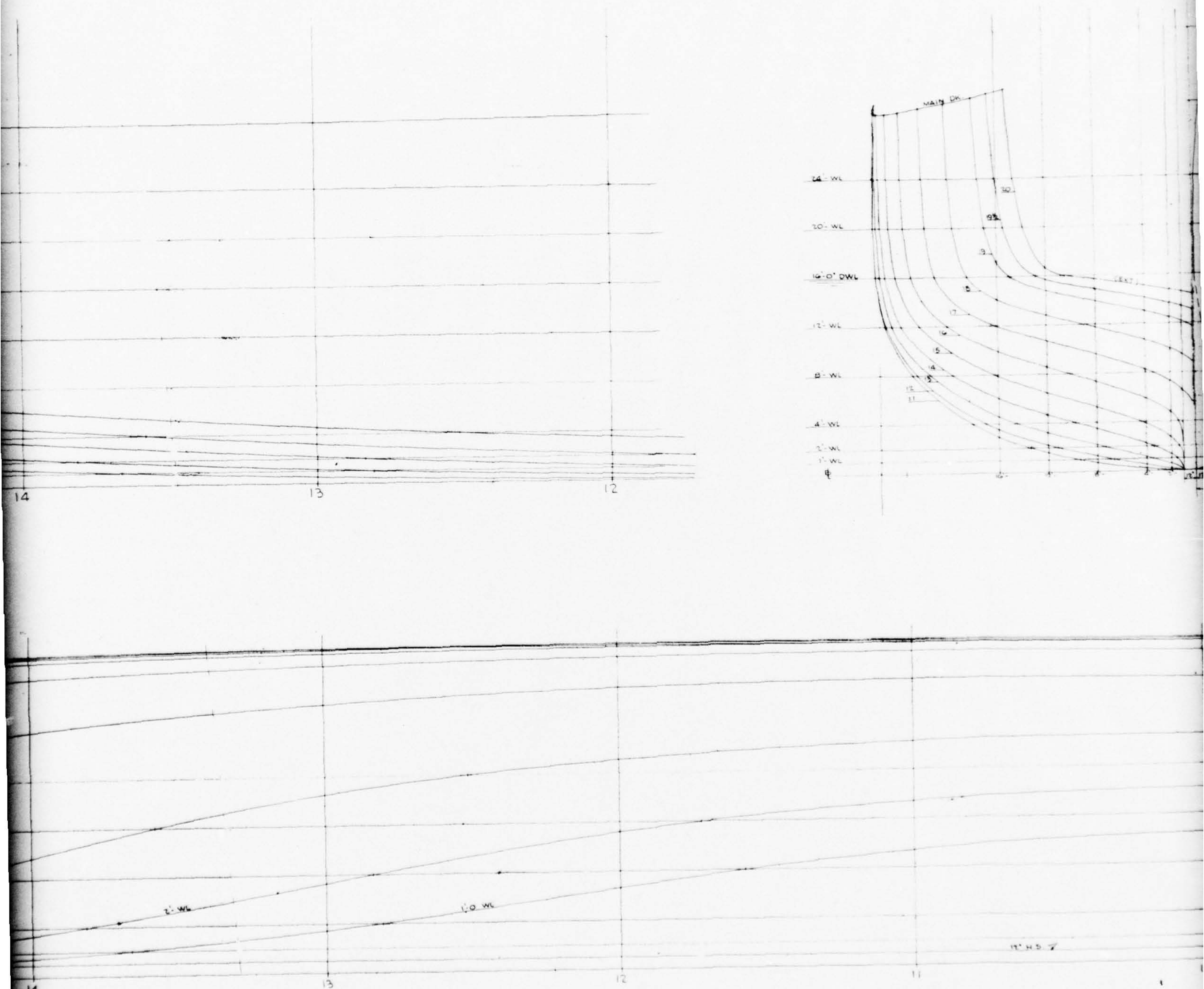

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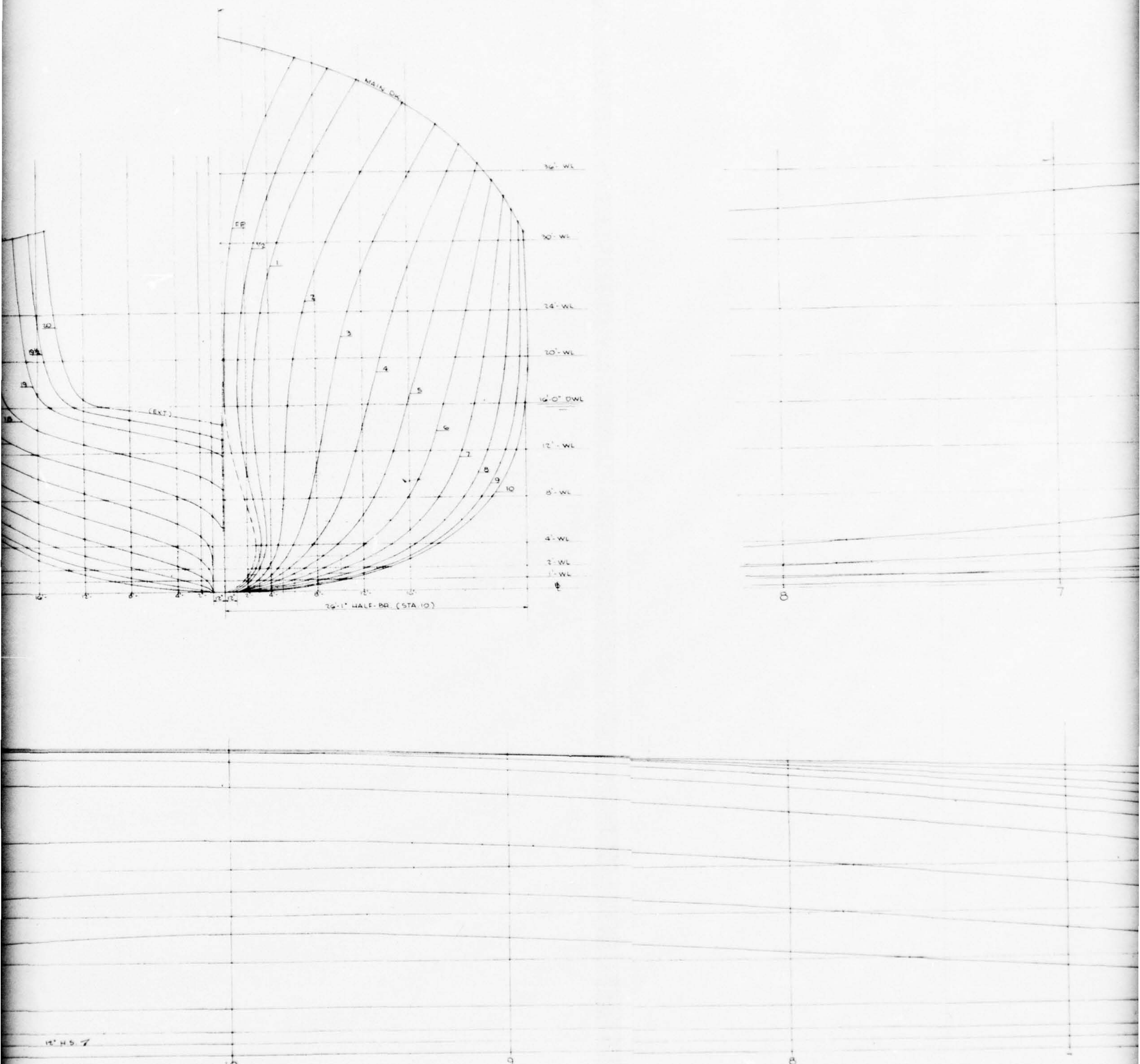
MAIN DK.
36'-WL
30'-WL
24'-WL
20'-WL
16'-0" DWL
12'-WL
8'-WL
4'-WL
2'-WL
1'-WL
FP
(EXT)
36'-1" HALF-BR. (STA. 10)
10
9
8
7

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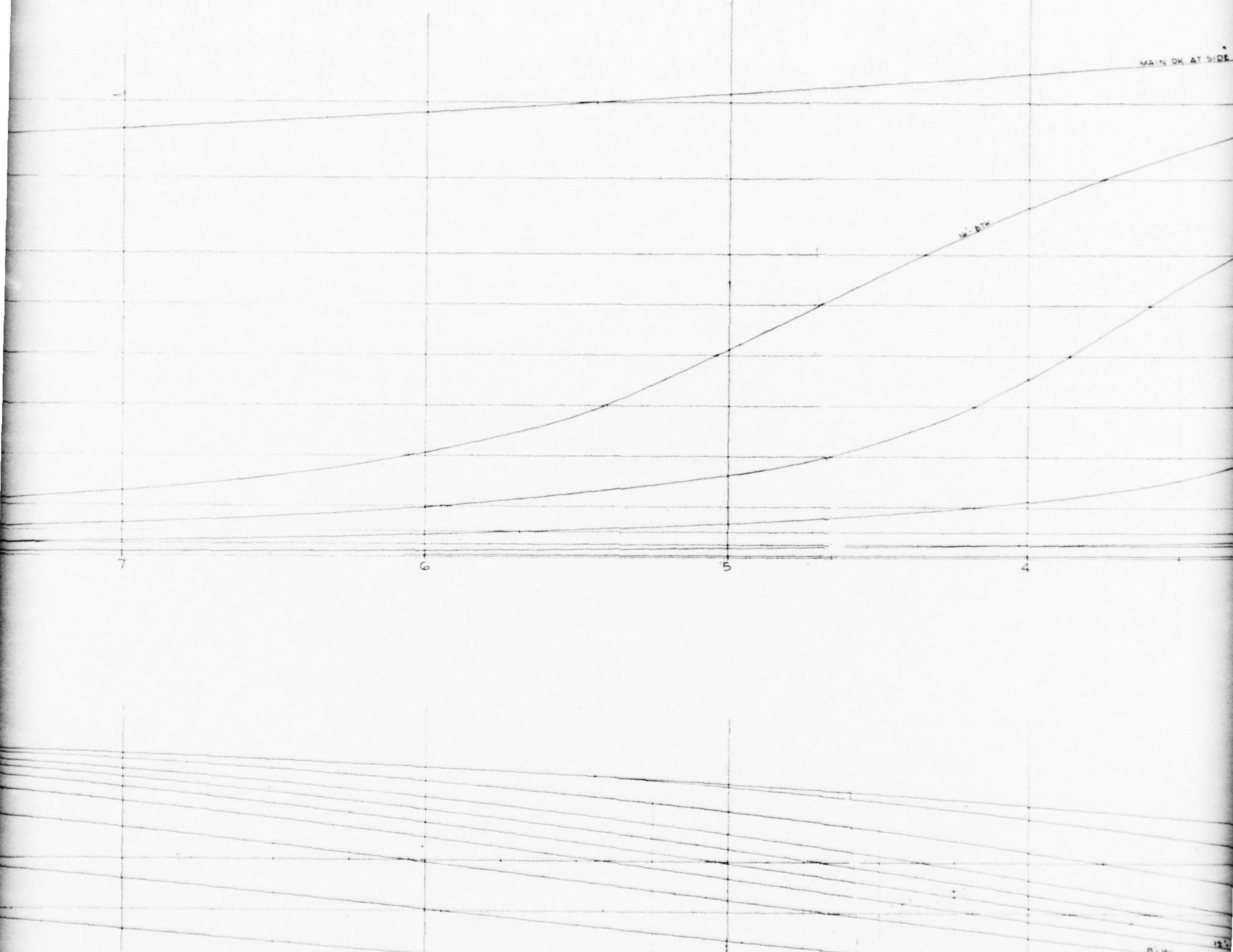

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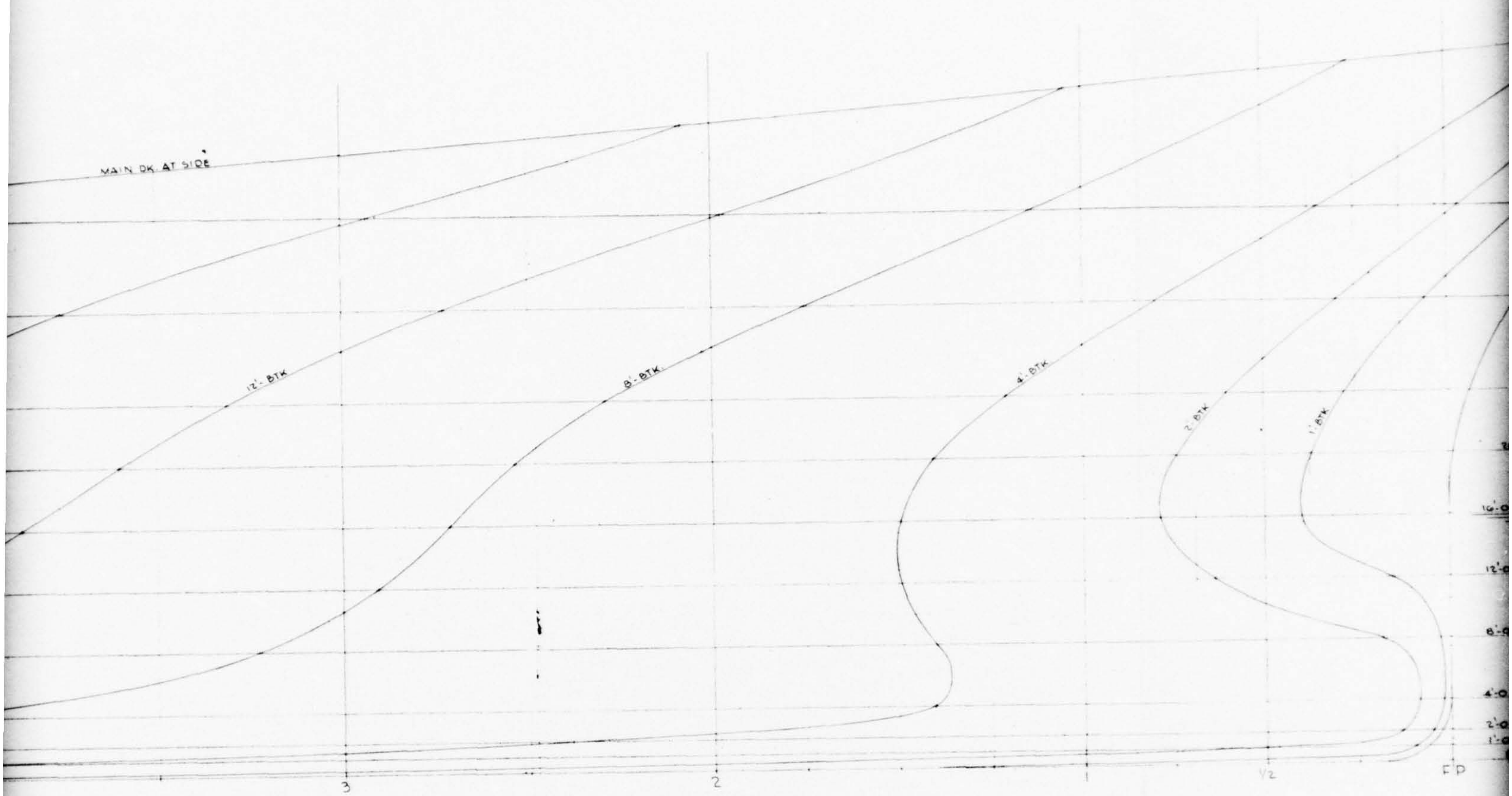
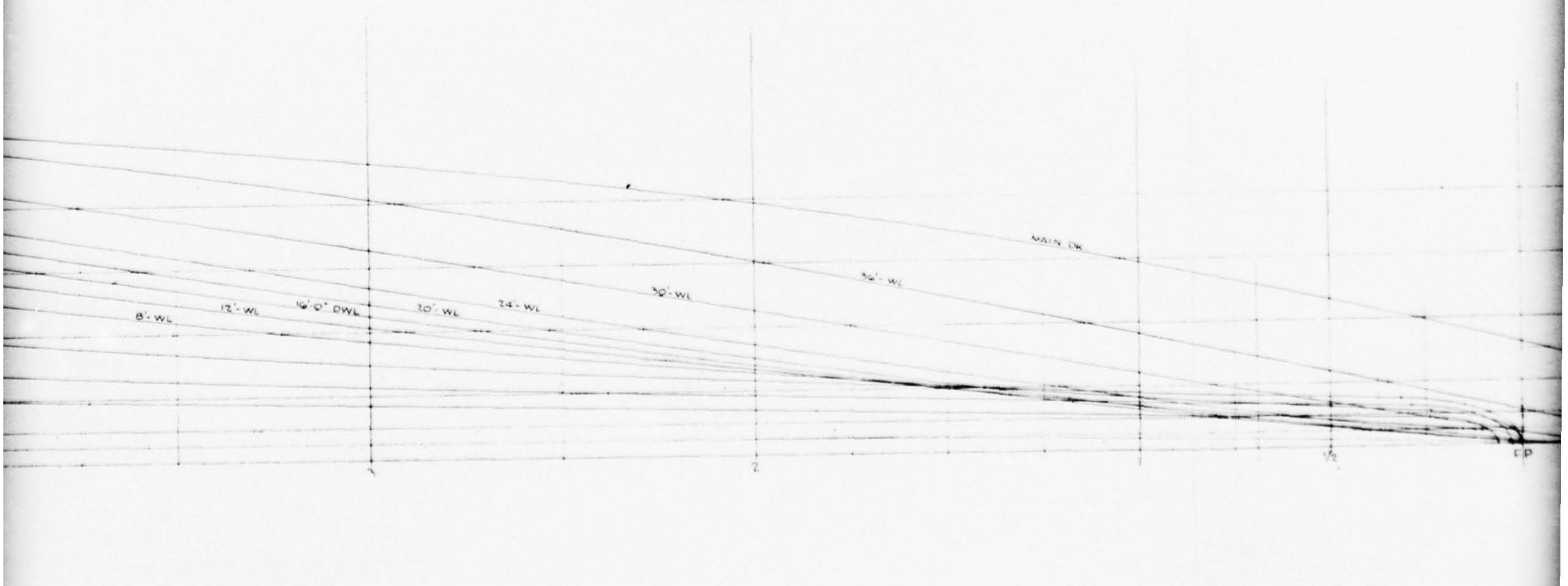


LENGTH BETW. PERPENDICULARS = 480'-0"
STATION SPACING = 24.0 FT.
LENGTH OVER ALL = 505'-0"



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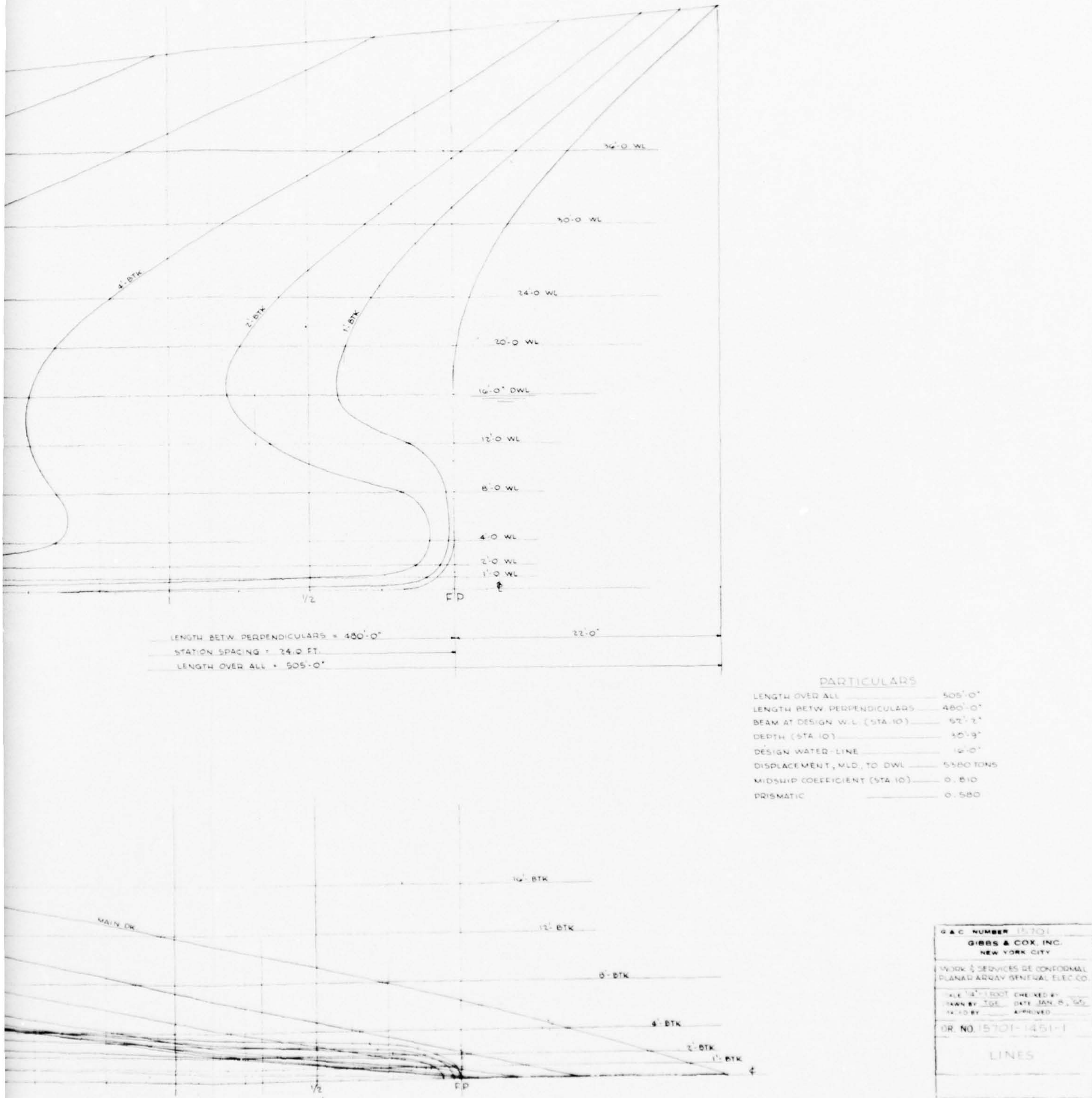


Figure 1. Lines Plan - Basic Hull Form

TABLE I

ARRAY DIMENSIONS AND LOCATION

Test Number	Array Dimensions			Vertical Location of Top of Array	Radius of Curvature of Dome	Bottom of Dome Below Base Line
	Width	Length	Thickness			
1	No	Array	- Basic Hull	- Tested for	Comparative Purposes	
2	7 feet	70 feet	12 inches	At Base Line	5 feet - 0 inch	3 feet - 3 inches
3	7 feet	70 feet	12 inches	1 foot - 6 inches above Base Line	5 feet - 0 inch	1 foot - 9 inches
4	7 feet	70 feet	12 inches	3 feet - 0 inch below Base Line	5 feet - 0 inch	6 feet - 3 inches
5	14 feet	70 feet	12 inches	At Base Line	10 feet - 0 inch	4 feet - 9 inches
6	14 feet	140 feet	12 inches	At Base Line	10 feet - 0 inch	4 feet - 9 inches
7	10 feet	70 feet	24 inches	At Base Line	7 feet - 0 inch	5 feet - 0 inch
8	10 feet	100 feet	24 inches	At Base Line	7 feet - 0 inch	5 feet - 0 inch
9	10 feet	100 feet	24 inches	1 foot - 6 inches above Base Line	7 feet - 0 inch	3 feet - 6 inches
10	Basic	Hull	With Standard Dome for AN/SQS-26 Tested for Comparative Purposes			
11	10 feet	70 feet	24 inches	3 feet - 0 inch above Base Line	7 feet - 0 inch	2 feet - 0 inch

The housings for the following arrays were developed and tested.

A. ARRAY 7 FEET - 0 INCH WIDE BY 12 INCHES DEEP BY 70 FEET LONG

Array housings for this array were developed with the top of the array in three different locations; at the baseline, 18 inches above the baseline and 3 feet - 0 inch below the baseline.

These different locations were selected to evaluate possible trade-offs between the effect of the sonar location on the ship performance and on the sonar performance.

The location of the top of the array on the baseline results in the minimum change in the usual ship's structure.

The location above the baseline with the array recessed into the hull will give the minimum increase in resistance at the lower speeds compared with the hull without the housing appendage and will also provide some shielding of the arrays by the hull of the ship to protect against interference by propeller noise.

The location below the baseline would give increased submergence for the planar array and possible better sonar performance, but would also result in an increase in power to drive the ship at the lower speeds.

Sections at the forward end of the array for these three array locations are shown on Figures 2, 3 and 4, respectively.

B. ARRAY - 14 FEET - 0 INCH BY 12 INCHES DEEP

Housings for two different lengths of array 70 feet and 140 feet were developed for this width of array to evaluate the effect of increasing the length of the array on the additional power requirements due to the housing. A section at the forward end of the array is shown on Figure 5. The longer housing will increase the difficulties of dry docking the ship and will therefore probably not be possible to adopt.

C. ARRAY - 10 FEET - 0 INCH BY 24 INCHES DEEP

Housings for this size array were developed for an array 70 feet - 0 inch long in two different locations, top of array at the baseline and 3 feet - 0 inch above the baseline; and for an array 100 feet long, 18 inches above the baseline. Sections at the forward end of the arrays are shown on Figures 6, 7 and 8, respectively. The lines for these domes are shown on Figures 9 and 10. The forward end of the dome has been located aft of the forward perpendicular, and the stem profile above and below the waterline has been modified from the basic lines to suit.

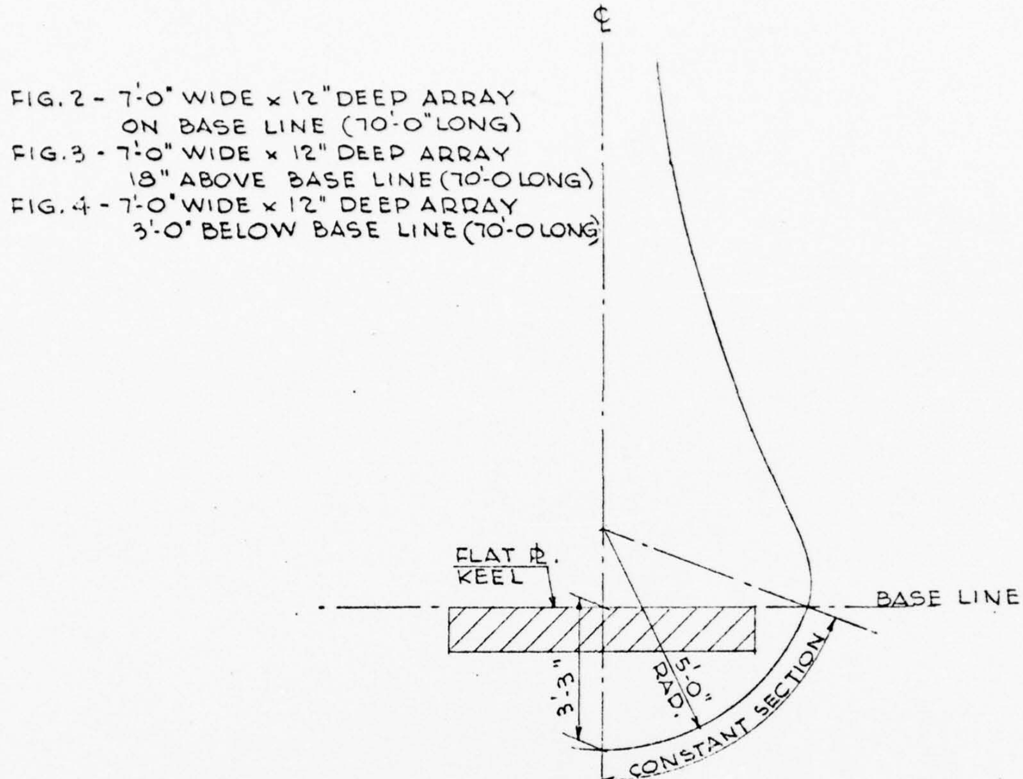


Figure 2. Array Housing Number 2

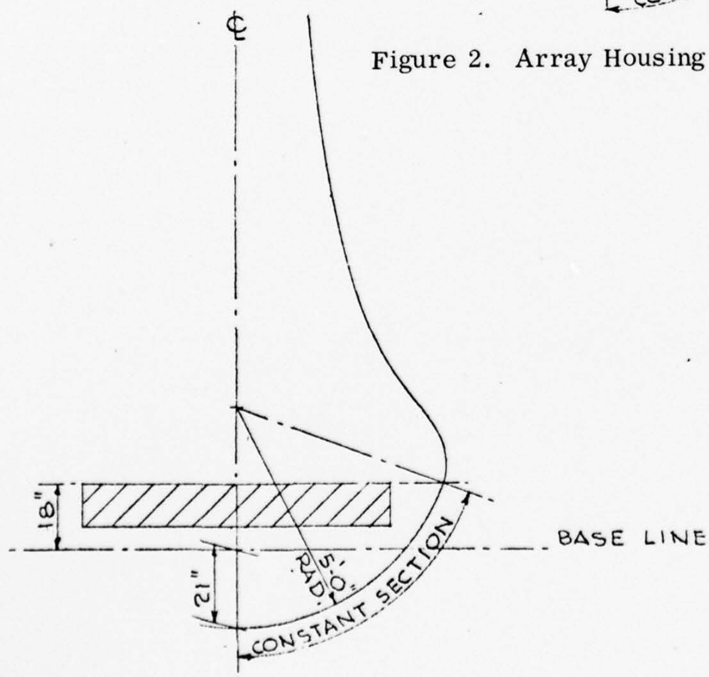


Figure 3. Array Housing Number 5

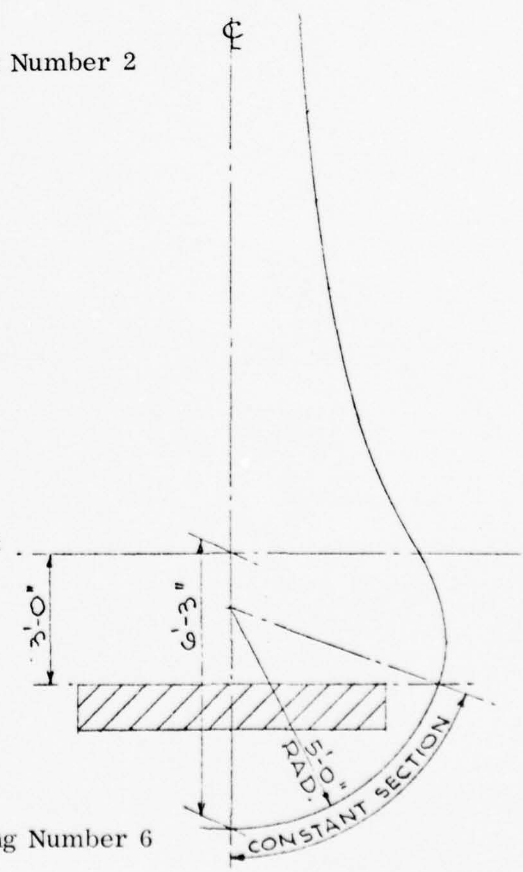


Figure 4. Array Housing Number 6

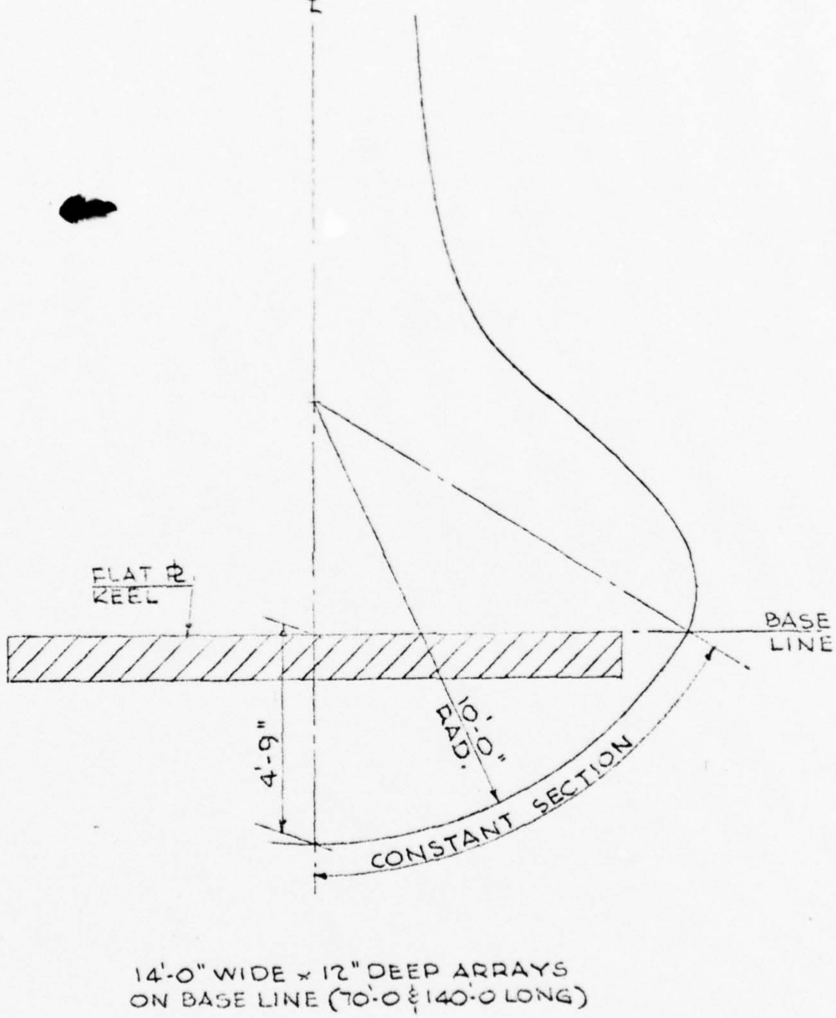


Figure 5. Array Housings Number 3 and 4

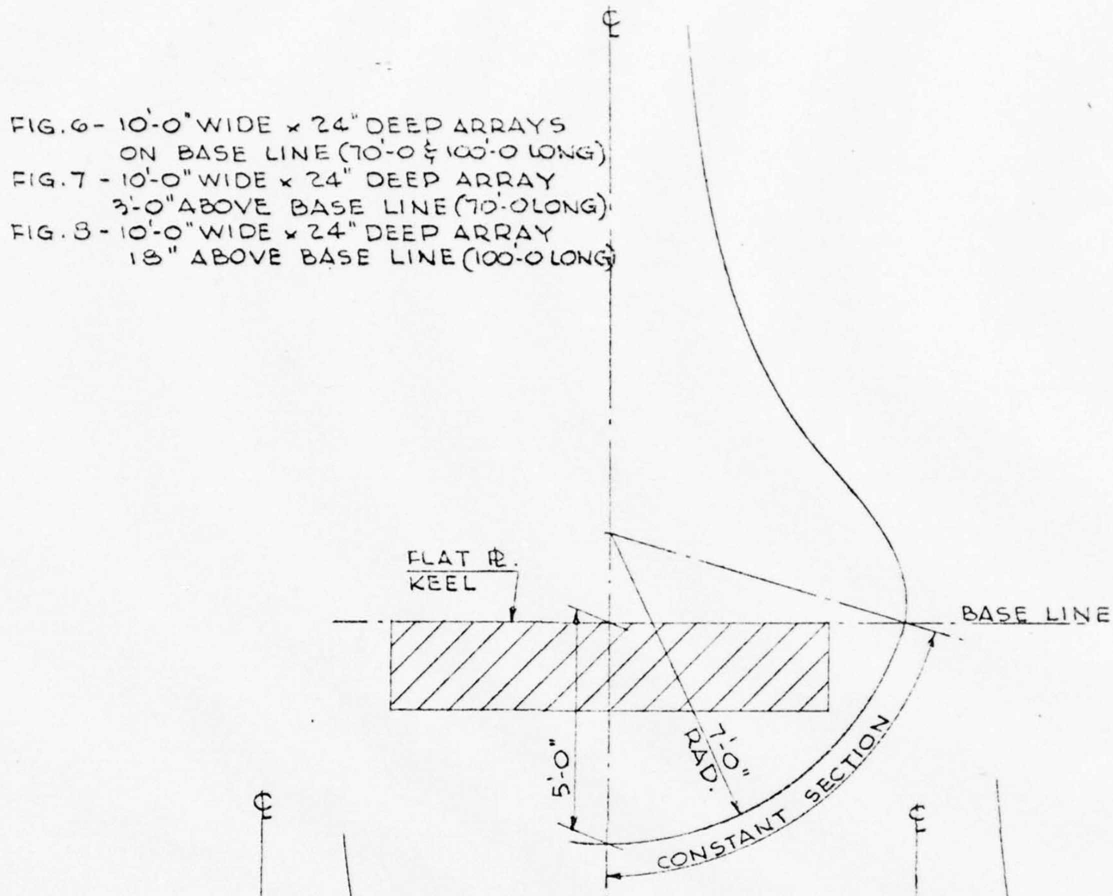


Figure 6. Array Housings
Number 7 and 8

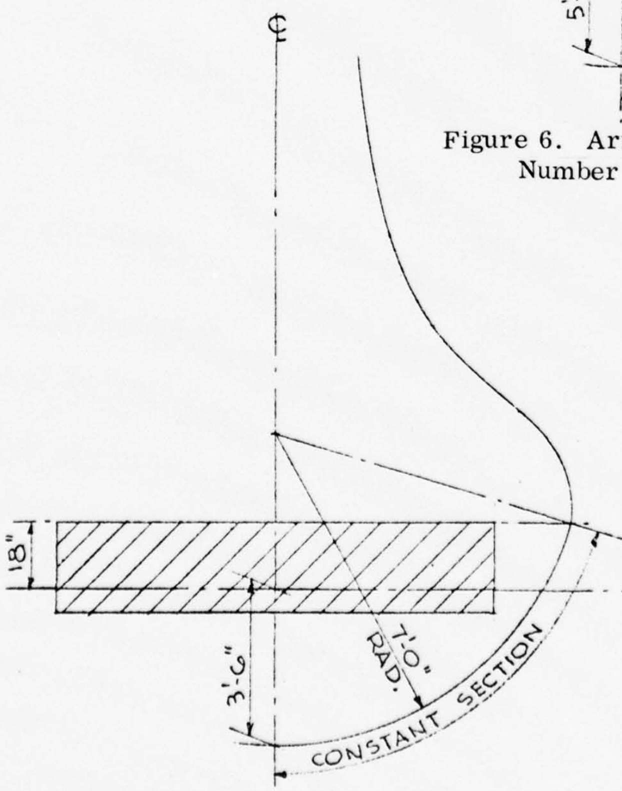


Figure 8. Array Housing Number 9

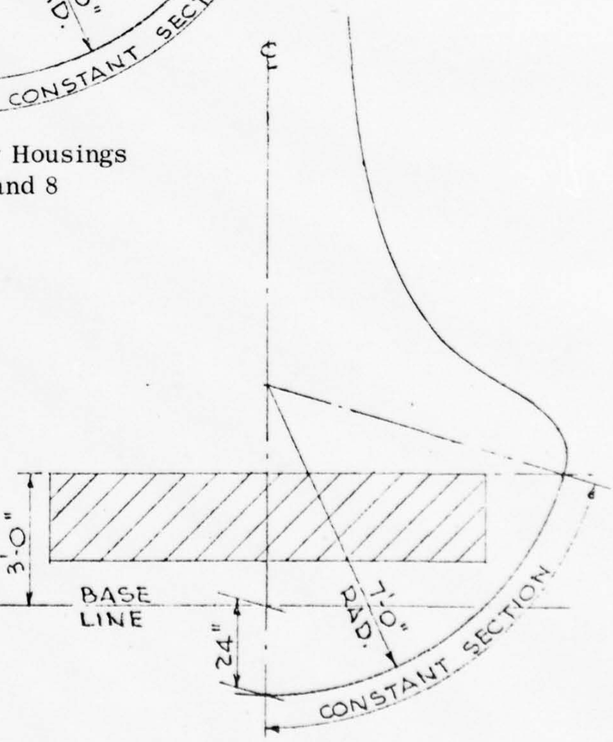
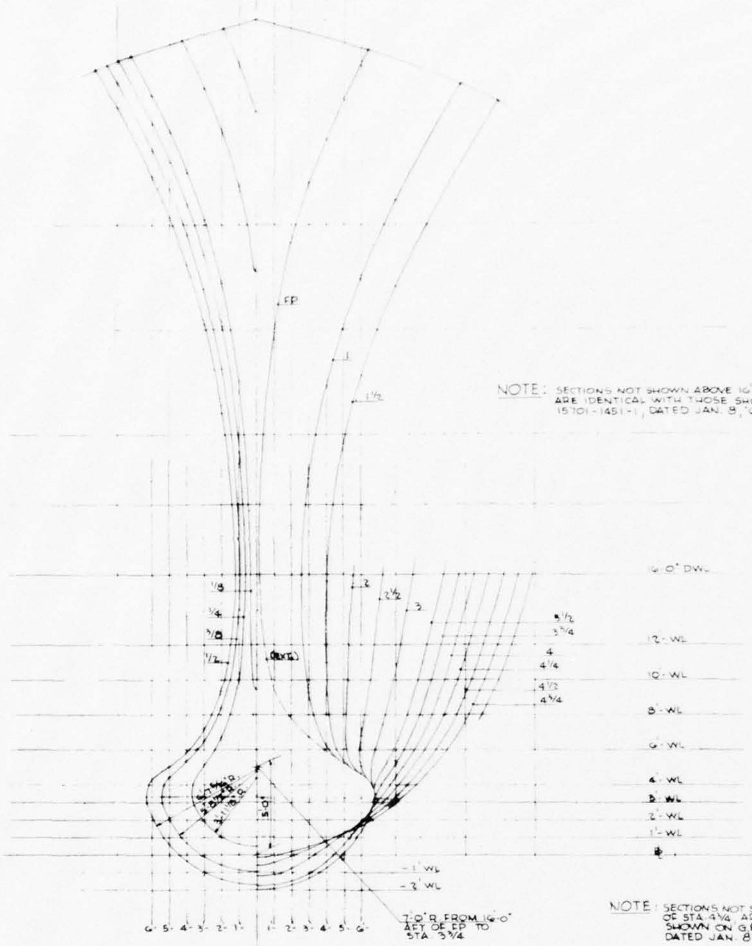


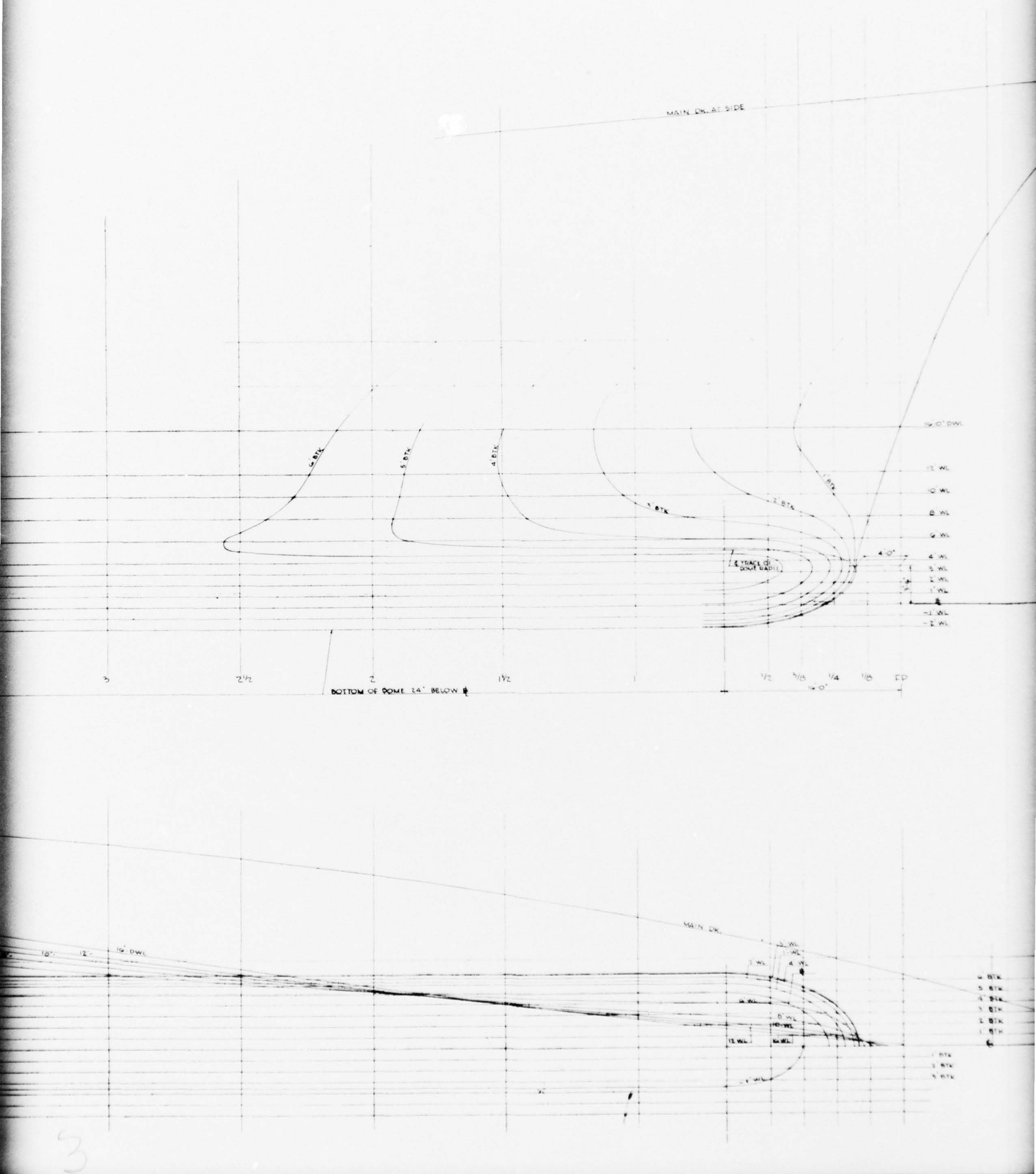
Figure 7. Array Housing Number 11



NOTE: SECTIONS NOT SHOWN ABOVE 16'-0" DWL AFT OF STA 1½ ABT., ARE IDENTICAL WITH THOSE SHOWN ON G.&C. DWG. NO. 15701-1451-1, DATED JAN. 8, '65.

NOTE: SECTIONS NOT SHOWN BELOW 16'-0" DWL & AFT OF STA 4¾, ARE IDENTICAL WITH THOSE SHOWN ON G.&C. DWG. NO. 15701-1451-1, DATED JAN. 8, '65.

5
4 3/4
4 1/2
4 1/4
4
3 3/4
3 1/2
3



MAIN DK. AT SIDE
16'-0" DWL
12' WL
10' WL
8' WL
6' WL
4' WL
3' WL
2' WL
1' WL
-1' WL
-2' WL
6' BTK
5' BTK
4' BTK
3' BTK
2' BTK
1' BTK
4'-0"
℄ TRACE OF DOME RADII
3
2½
2
1½
1
½
3/8
1/4
1/8
FP
6'-0"
BOTTOM OF DOME 24" BELOW ℄
MAIN DK.
16' DWL
12 WL
6 WL
8' WL
10 WL
16 WL

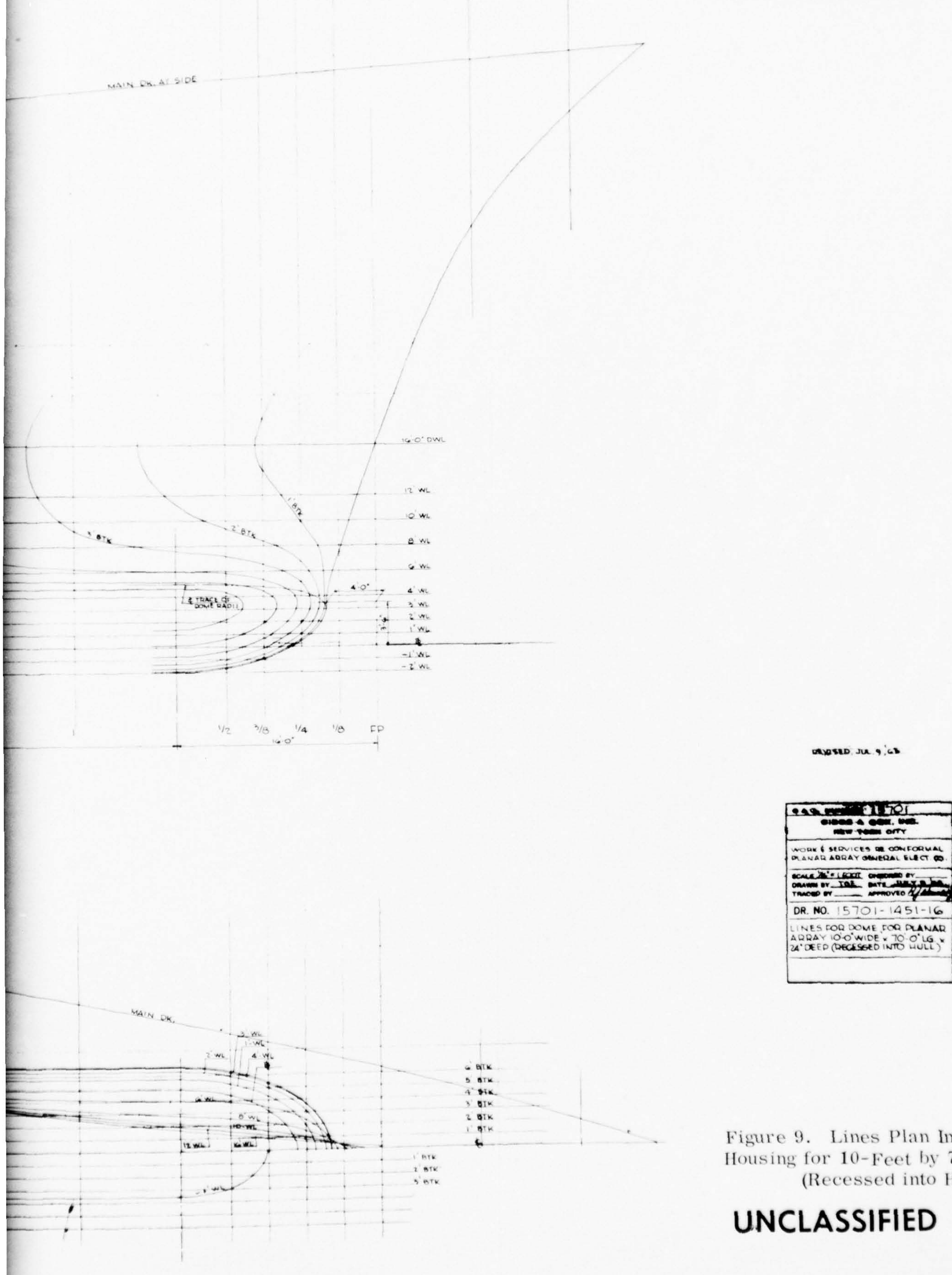
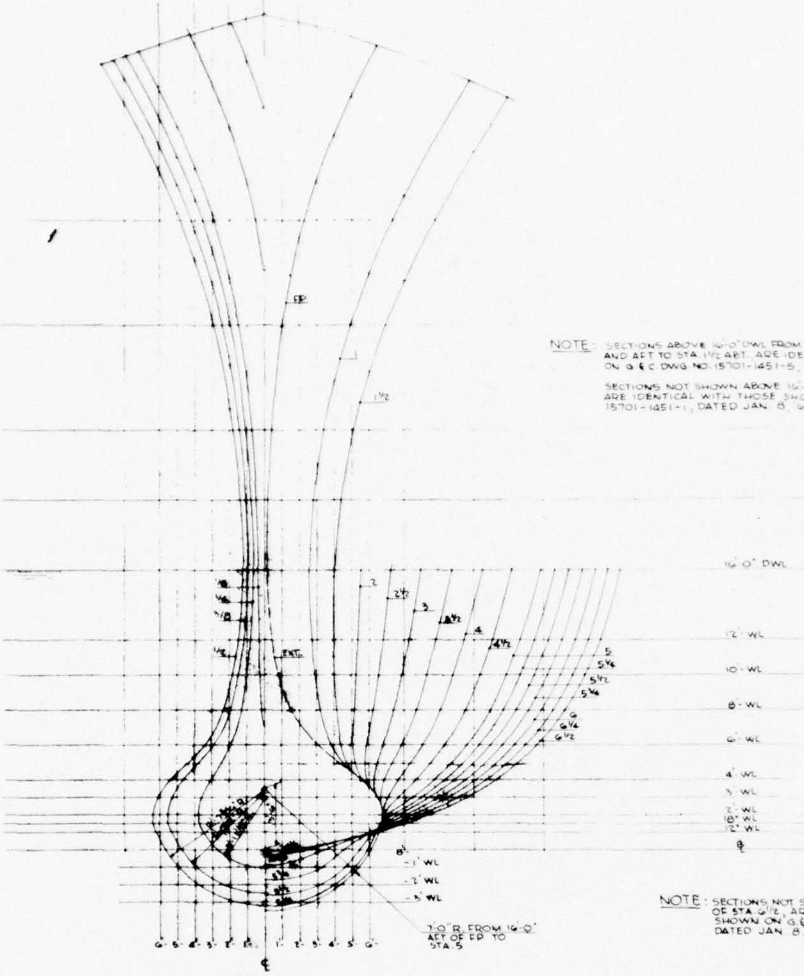


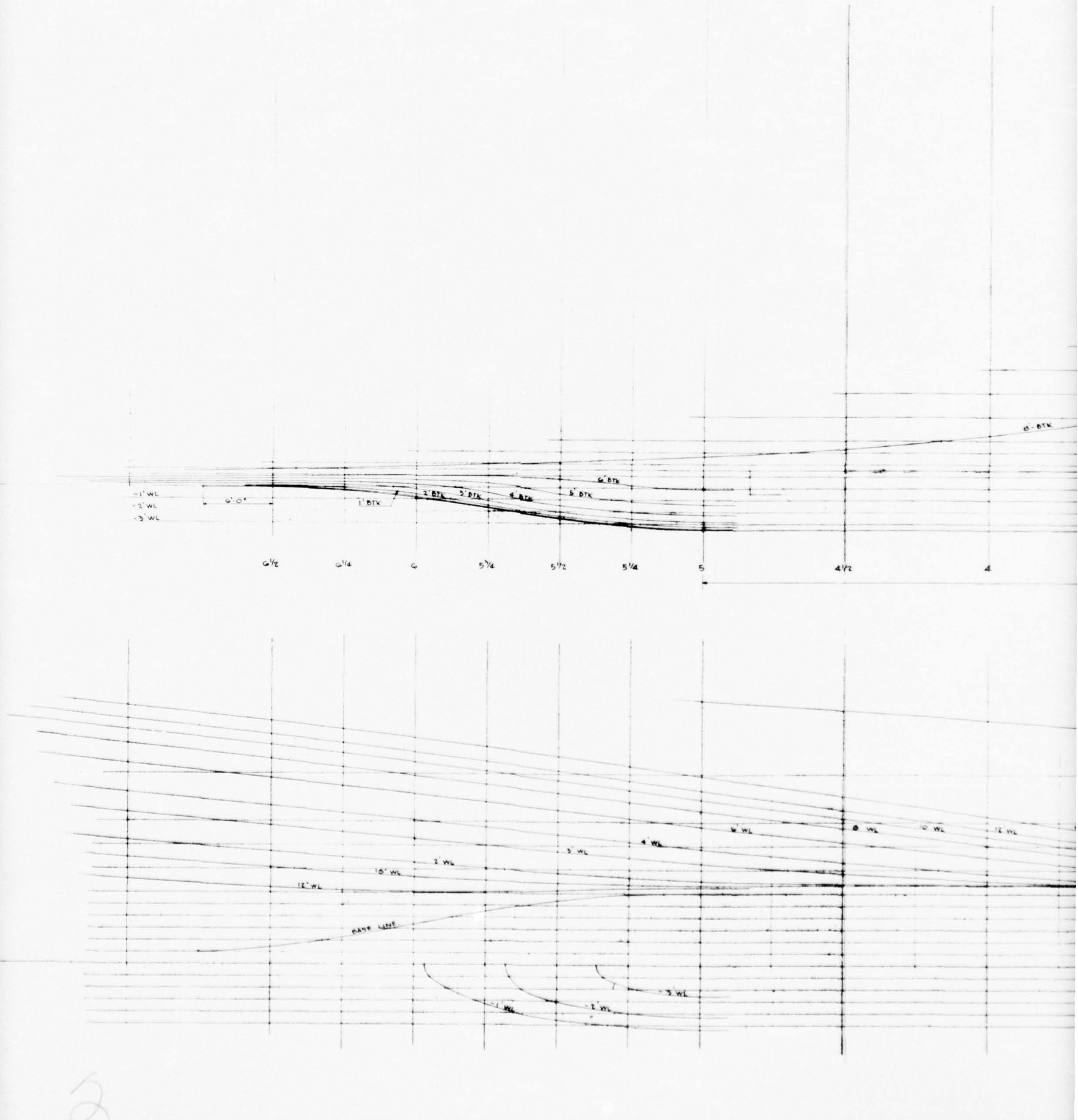
Figure 9. Lines Plan Incorporating Housing for 10-Feet by 70-Feet Array (Recessed into Hull)



NOTE: SECTIONS ABOVE 16'-0" DWL FROM MAIN DK. STEM OVERHANG AND AFT TO STA. 1½ ABT., ARE IDENTICAL WITH THOSE SHOWN ON G & C. DWG. NO. 15701-1451-5, DATED FEB. 19, '65.

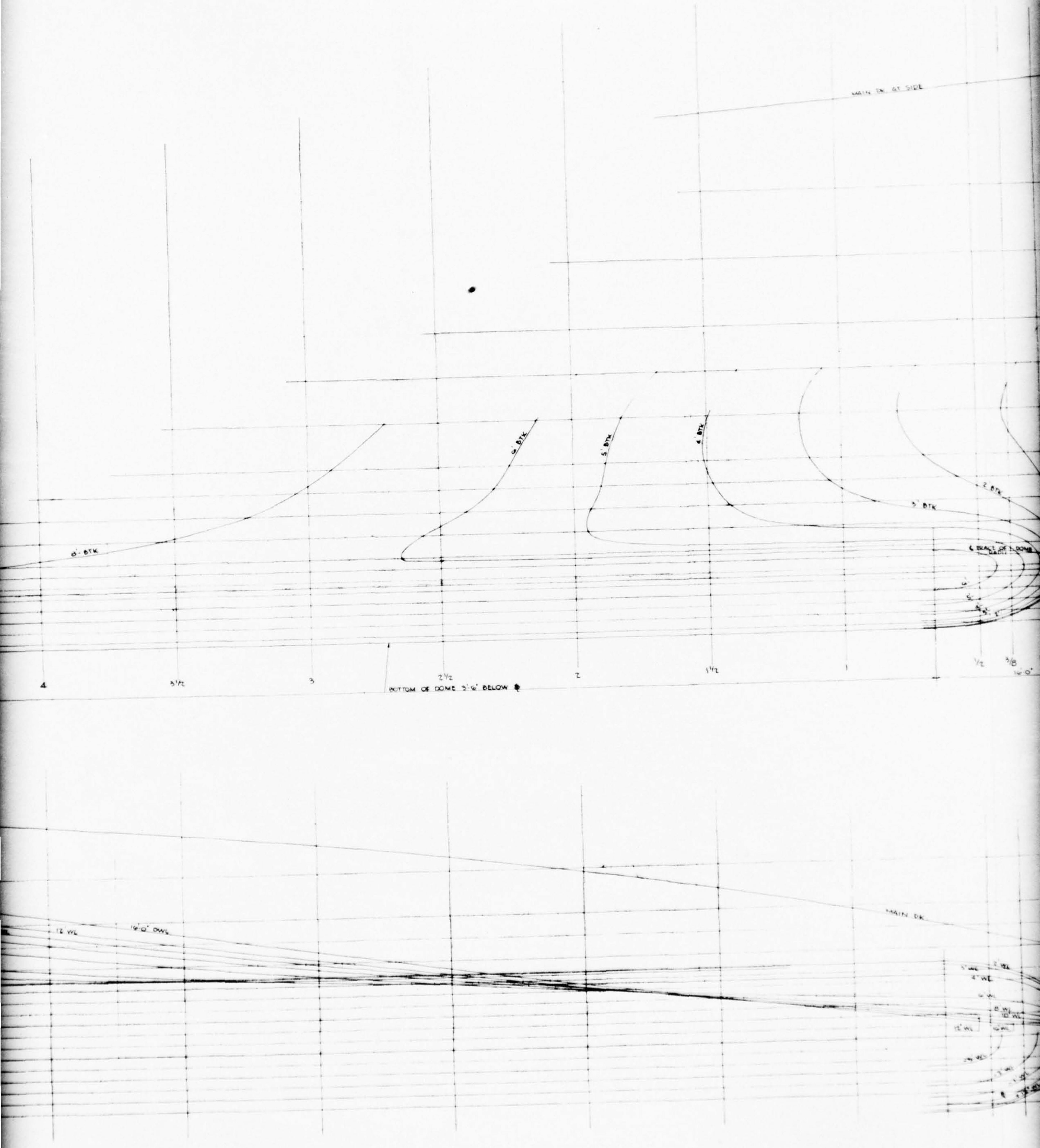
SECTIONS NOT SHOWN ABOVE 16'-0" DWL AFT OF STA. 1½ ABT., ARE IDENTICAL WITH THOSE SHOWN ON G & C. DWG. NO. 15701-1451-1, DATED JAN. 8, '65.

NOTE: SECTIONS NOT SHOWN BELOW 16'-0" DWL & A' OF STA. 6½, ARE IDENTICAL WITH THOSE SHOWN ON G. & C. DWG. NO. 15701-1451-1, DATED JAN. 8, '65.



-1' WL
-2' WL
-3' WL
6'-0"
1' BTK
2' BTK
3' BTK
4' BTK
5' BTK
6' BTK
8' BTK
6 1/2
6 1/4
6
5 3/4
5 1/2
5 1/4
5
4 1/2
4
6' WL
8' WL
10' WL
12' WL
4' WL
3' WL
2' WL
BASE LINE
-1' WL
-2' WL
-3' WL

2


MAIN DK AT SIDE
8' BTK
6' BTK
5' BTK
4' BTK
3' BTK
2' BTK
4
3 1/2
3
2 1/2
2
1 1/2
1
1/2
3/8
16'0"
BOTTOM OF DOME 3'-6" BELOW ℄
MAIN DK
12 WL
16'0" DWL

3

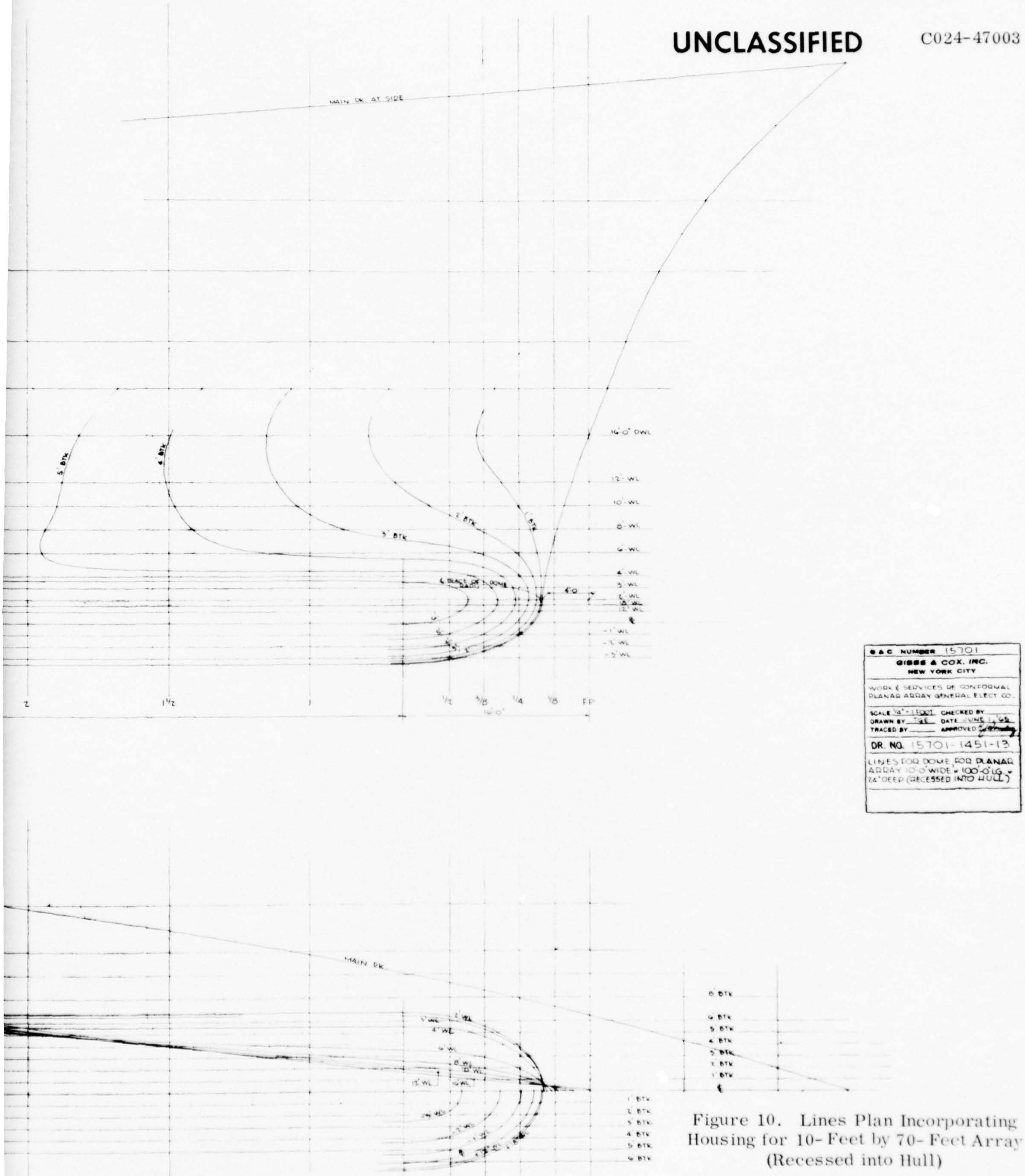


Figure 10. Lines Plan Incorporating Housing for 10-Feet by 70-Feet Array (Recessed into Hull)

4

D. COMPARATIVE STUDY

For comparative purposes, a dome suitable for housing an AN/SQS-26 sonar transducer was also tested.

Two different depths of arrays were utilized in developing the housings used in these studies, namely 12 inches and 24 inches. These two dimensions were selected since they will accommodate transducer elements of different size, construction, and mounting details; either of which might be selected ultimately for the Conformal/Planar Array Sonar System.

In general, the transverse sections of the array housings are circular, and of a radius selected as a compromise between the smallest permissible envelope appendage and a larger radius which would reduce the area subject to lateral forces due to cross flow when the ship is turning and when the ship is operating in a seaway. The forward end of the array appendage is circular in cross section, with both the horizontal sections and vertical fore and aft sections being elliptical. The after end is suitably faired into the hull. These array housings were designed to incorporate a pressurized rubber window below and in front of the sonar transducer face. This sonar window, or dome, when pressurized would assume the semi-circular cross section shape; and by keeping its radius to a minimum, the internal structural stresses in the dome would be minimal. The lower portion of the array housing, or sonar window, could also be fabricated of fiberglas, steel or other suitable material without altering its basic shape.

Analytical studies for predicting the relative sonar performance capabilities for these various size transducer arrays were conducted concurrently with the ship model tests described herein, as a part of the trade-off studies of hydrodynamic versus sonar performance. Based on the results of the preliminary trade-off analysis between sonar and ship performance, housings for a 10 feet wide by 24 inches deep array were selected for further testing at the David Taylor Model Basin (DTMB). Two lengths of housings will be tested, one for a 70 feet - 0 inch long array and one for a 100 feet - 0 inch long array. Both of these arrays are to be recessed into the hull. The lines of these housings are shown on Figures 9 and 10.

SECTION III
TEST RESULTS

Model tests were conducted at the Davidson Laboratory of the Stevens Institute of Technology, Hoboken, New Jersey, for nine different planar array housing configurations. For comparative purposes, tests were also run for the basic destroyer hull with a normal bow, and for the basic hull fitted with a standard AN/SQS-26 bow dome. Figures 11 and 12 show typical models used in these tests.

Measurements of model resistance and bow and stern sinkage or rise were made for ship speeds between 10 and 40 knots for each configuration. All tests were run in still water. Resistance data were expanded to full scale using the Schoenherr mean line with a roughness allowance of 0.0004. Tabulations of these results, as received from the Davidson Laboratory, are included herein as Tables II through V and VII through XII. Data given in Table VI are revisions of Davidson Laboratory calculations, which were made as a result of modifications to the fairing of the basic model resistance data.

All model tests were run at a constant draft corresponding to a full scale draft of 16 feet. This procedure was adopted since all housings considered in this report are internally floodable. The displacement, therefore, is dependent on the size of the housing.

Wave profile photographs were taken at speeds of approximately 20, 25, 35 and 40 knots during each test. A number of representative photographs, Figures 13 to 28, are included in this report.

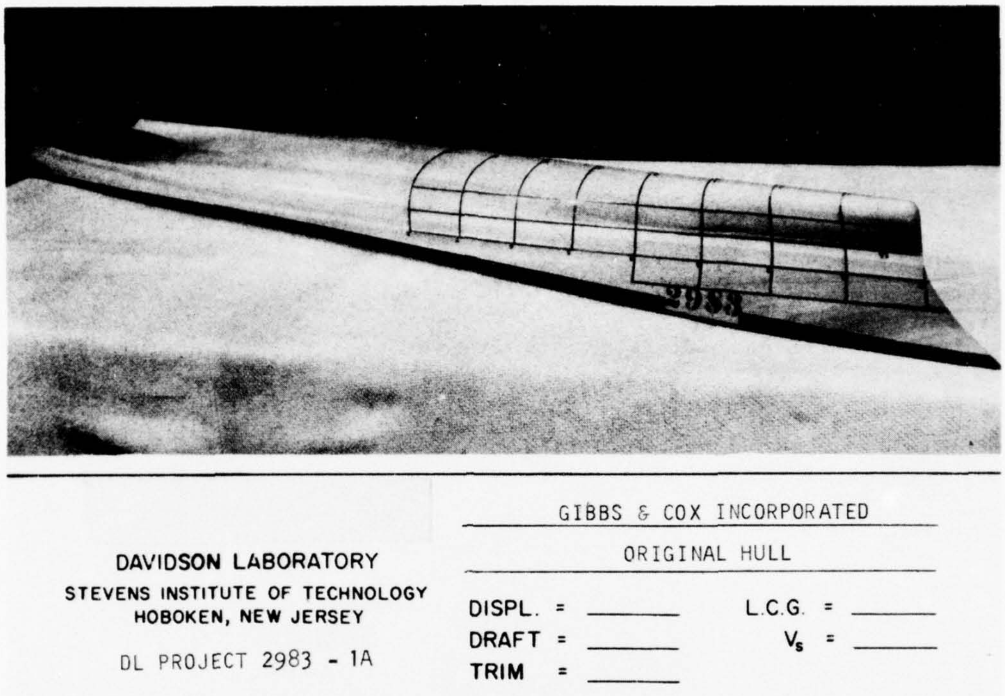


Figure 11. Model Photo of Basic Hull

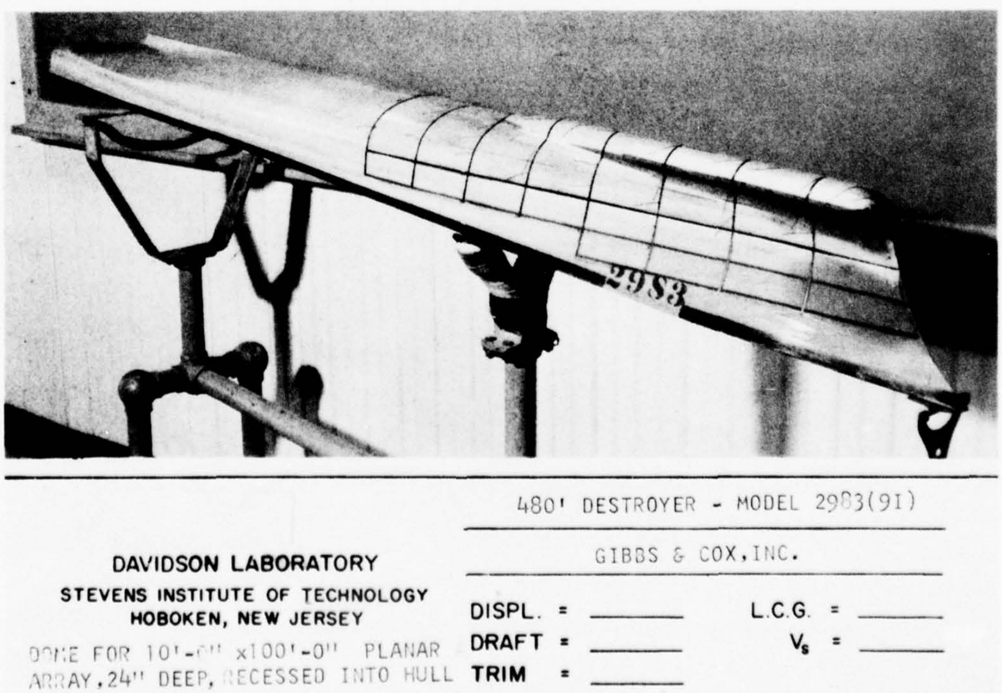


Figure 12. Model Photo of 10' by 100' Recessed, Housing Number 9

TABLE II

DAVIDSON LABORATORY TABLE OF EHP AND TRIM TEST RESULTS, TEST NUMBER 1A

(NO APPENDAGES)

Displacement . . . 5,380 tons

Wetted Area . . . 25,470 ft^2

V_s knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	741.3	0	0
12.68	1,219	-0.67	0
14.78	1,851	-0.67	-0.20
16.89	2,837	-0.67	-0.33
18.29	3,704	-1.33	-0.67
20.38	5,088	-1.33	-0.67
22.95	7,377	-2.00	-1.00
24.85	9,893	-2.00	-1.00
26.74	14,060	-2.67	-1.33
28.61	20,050	-1.67	-2.67
30.50	27,430	-1.00	-3.67
32.41	36,420	0	-4.67
34.32	46,165	+1.00	-6.00
36.21	56,150	+1.00	-6.00
38.10	67,580	+3.33	-8.00
40.02	79,370	+2.67	-6.67

TABLE III

DAVIDSON LABORATORY TABLE OF EHP AND TRIM TEST RESULTS, TEST NUMBER 2B

(DOME FOR 7' x 70' PLANAR ARRAY)

Displacement . . . 5,464 tons

Wetted Area . . . 26,190 ft^2

V_s knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	771.2	0	0
12.68	1,297	-0.67	-0.33
14.78	1,994	-1.00	-0.67
16.89	3,006	-1.20	-0.67
18.29	3,819	-1.33	-0.80
20.38	5,214	-1.47	-1.00
22.95	7,553	-1.67	-1.00
24.85	10,130	-2.33	-1.20
26.74	13,970	-2.53	-1.33
28.61	19,590	-1.67	-1.47
30.50	27,670	-1.33	-3.33
32.41	36,740	-1.00	-4.00
34.32	45,970	+0.67	-5.67
36.21	55,980	+0.67	-6.33
38.10	66,810	+2.33	-6.67
40.02	78,670	+3.33	-7.00

TABLE IV

DAVIDSON LABORATORY TABLE OF EHP AND TRIM TEST RESULTS, TEST NUMBER 3C

(DOME FOR 14' x 70' PLANAR ARRAY)

Displacement . . . 5,668 tons

Wetted Area . . . 27,020 ft^2

V_s knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	801.9	-0.33	0
12.68	1,363	-0.67	0
14.78	2,147	-1.00	0
16.89	3,382	-1.33	0
18.29	4,455	-1.67	0
20.38	6,216	-1.67	0
22.95	9,008	-2.00	0
24.85	11,528	-2.67	0
26.74	14,987	-2.67	0
28.61	20,851	-3.33	-1.33
30.50	28,507	-2.00	-2.67
32.41	37,791	-1.33	-3.33
34.32	48,047	-1.33	-4.00
36.21	58,070	-0.67	-5.33
38.10	67,293	+1.67	-6.67
40.02	76,728	+3.00	-7.33

TABLE V

DAVIDSON LABORATORY TABLE OF EHP AND TRIM TEST RESULTS, TEST NUMBER 4D

(DOME FOR 14' x 140' PLANAR ARRAY)

Displacement . . . 5,807 tons

Wetted Area . . . 27,420 ft^2

V_s Knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	754.0	0	0
12.68	1,310.	-0.33	0
14.78	2,132.	-0.67	0
16.89	3,262.	-1.20	0
18.29	4,201.	-1.33	0
20.38	5,943.	-1.67	0
22.95	8,508.	-2.00	0
24.85	11,004.	-2.67	-0.33
26.74	14,350.	-3.20	-0.80
28.61	20,665.	-3.00	-1.30
30.50	28,340	-2.33	-3.33
32.41	37,640	-1.67	-4.00
34.32	47,820	-1.33	-5.67
36.21	57,600	-0.67	-6.00
38.10	67,100	+2.00	-7.33
40.02	76,500	+2.67	-7.67

TABLE VI

TABLE OF EHP (REVISED) AND TRIM TEST RESULTS, TEST NUMBER 5E

(DOME FOR 7' - 0" x 70' - 0" PLANAR ARRAY, RECESSED INTO HULL)

Displacement . . . 5,416 tons

Wetted Area . . . 25,770 ft^2

V_s Knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	689	0	0
12.68	1,182	0	0
14.78	1,876	-0.67	0
16.89	2,819	-1.00	0
18.29	3,637	-1.33	0
20.38	5,115	-1.33	0
22.95	7,239	-1.67	-0.33
24.85	9,709	-2.43	-0.67
26.74	13,627	-2.77	-1.00
28.61	19,433	-2.33	-1.33
30.50	27,545	-1.43	-3.34
32.41	37,426	-0.33	-4.44
34.32	47,386	0	-5.00
36.21	57,022	+0.33	-6.34
38.10	66,247	+2.10	-6.67
40.02	74,942	+3.34	-6.67

TABLE VII

DAVIDSON LABORATORY TABLE OF EHP AND TRIM TEST RESULTS, TEST NUMBER 6F

(DOME FOR 7'0" x 70'0" PLANAR ARRAY - TOP OF ARRAY 3' - 0" BELOW BASELINE)

Displacement . . . 5,525 tons

Wetted Area . . . 26,770 ft^2

V_S Knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	731.3	-0.67	0
12.68	1,218	-1.00	0
14.78	1,883	-1.20	0
16.89	2,878	-1.33	0
18.29	3,791	-1.40	0
20.38	5,337	-1.67	0
22.95	7,955	-2.00	-0.20
24.85	10,229	-2.33	-0.67
26.74	13,673	-2.53	-1.00
28.61	19,767	-2.67	-1.33
30.50	27,309	-2.00	-2.67
32.41	36,867	-1.20	-4.00
34.32	46,270	0	-5.33
36.21	57,161	+0.67	-6.00
38.10	64,913	+1.33	-6.67
40.02	72,287	+2.00	-7.33

TABLE VIII

DAVIDSON LABORATORY TABLE OF EHP AND TRIM TEST RESULTS, TEST NUMBER 7G

(DOME FOR 10' - 0" x 70' - 0" PLANAR ARRAY; 24" DEEP)

Displacement . . . 5,566 tons

Wetted area . . . 26,690 ft^2

V_s Knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	802.7	0	0
12.68	1,336	-0.47	0
14.78	2,099	-0.67	0
16.89	3,231	-1.00	0
18.29	4,191	-1.33	0
20.38	5,883	-1.47	0
22.95	8,338	-2.00	0
24.85	10,500	-2.67	-0.67
26.74	14,280	-3.00	-1.00
28.61	19,890	-3.00	-1.33
30.50	27,920	-2.00	-3.33
32.41	37,260	-1.33	-3.67
34.32	46,730	0	-5.67
36.21	56,140	+1.33	-7.33
38.10	65,320	+1.67	-8.00
40.02	74,180	+2.67	-8.00

TABLE IX

DAVIDSON LABORATORY TABLE OF EHP AND TRIM TEST RESULTS
TEST NUMBER 8H

(DOME FOR 10' - 0" x 100' - 0" PLANAR ARRAY; 24" DEEP)

Displacement . . . 5,618 tons

Wetted Area . . . 26,920 ft^2

V_s Knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	868.3	0	0
12.68	1,454	0	0
14.78	2,253	-0.33	0
16.89	3,313	-0.67	0
18.29	4,240	-1.00	0
20.38	5,991	-1.33	0
22.95	8,521	-1.80	-0.33
24.85	10,770	-2.67	-0.67
26.74	14,310	-3.33	-1.00
28.61	20,060	-3.00	-1.33
30.50	27,610	-1.67	-3.33
32.41	36,860	-0.67	-4.00
34.32	47,020	0	-5.00
36.21	56,950	+1.33	-6.33
38.10	66,795	+2.67	-7.00
40.02	77,320	+3.33	-8.00

TABLE X

DAVIDSON LABORATORY TABLE OF EHP AND TRIM TEST RESULTS, TEST NUMBER 91

(DOME FOR 10' - 0" x 100' - 0" PLANAR ARRAY; 24" DEEP; RECESSED INTO HULL)

Displacement . . . 5,552 tons

Wetted Area . . . 26,490 ft^2

V_s Knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	813.1	0	0
12.68	1,354	-0.67	0
14.78	2,134	-0.80	0
16.89	3,207	-1.20	0
18.29	4,101	-1.47	0
20.38	5,743	-1.67	0
22.95	7,999	-2.00	0
24.85	10,170	-2.80	-0.47
26.74	13,770	-3.00	-1.33
28.61	19,420	-2.80	-1.67
30.50	27,380	-2.00	-3.33
32.41	37,380	-1.00	-4.00
34.32	47,500	0	-5.33
36.21	57,700	+0.67	-6.66
38.10	66,370	+2.00	-7.33
40.02	74,510	+2.67	-7.67

TABLE XI

DAVIDSON LABORATORY TABLE OF EHP AND TRIM TEST RESULTS,
TEST NUMBER 10J

(AN/SQS-26 TRANSDUCER DOME)

Displacement . . . 5,514 tons

Wetted Area . . . 26,700 ft^2

V_s Knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	1,044	0	0
12.68	1,768	-0.33	0
14.78	2,661	-0.67	0
16.89	3,769	-1.20	0
18.29	4,658	-1.33	0
20.38	6,163	-1.47	0
22.95	8,563	-1.87	0
24.85	10,890	-2.33	-0.33
26.74	14,490	-2.67	-0.80
28.61	20,590	-2.67	-1.67
30.50	29,160	-2.00	-2.67
32.41	38,750	-1.00	-3.33
34.32	49,340	0	-4.67
36.21	59,300	+0.67	-6.67
38.10	67,600	+2.67	-8.00
40.02	78,880	+2.67	-8.00

TABLE XII

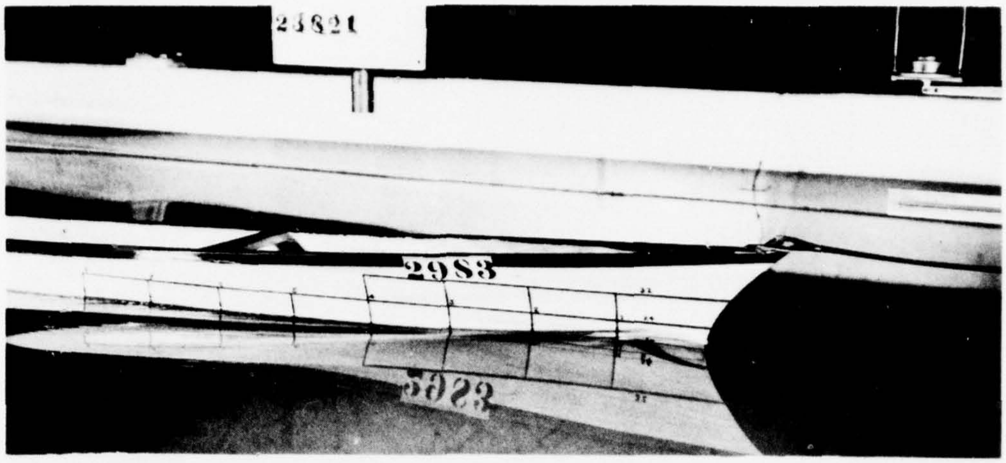
DAVIDSON LABORATORY TABLE OF EHP AND TRIM TEST RESULTS, TEST NUMBER 11K

(DOME FOR 10' - 0" x 70' - 0" x 24" DEEP PLANAR ARRAY RECESSED INTO HULL)

Displacement . . . 5,469 tons

Wetted Area . . . 26,040 ft^2

V_s Knots	EHP	Trim ft	
		Sta 0	Sta 20
10.57	800.1	0	0
12.68	1,344	-0.33	0
14.78	2,132	-0.67	0
16.89	3,208	-1.00	0
18.29	4,071	-1.33	0
20.38	5,647	-1.67	0
22.95	8,084	-2.00	0
24.85	10,410	-2.33	-0.33
26.74	13,920	-2.53	-0.80
28.61	19,930	-2.67	-1.33
30.50	27,870	-1.67	-3.00
32.41	36,870	-0.67	-4.00
34.32	47,220	0	-5.33
36.21	57,100	+0.67	-6.67
38.10	65,290	+2.00	-7.33
40.02	75,460	+3.00	-7.33



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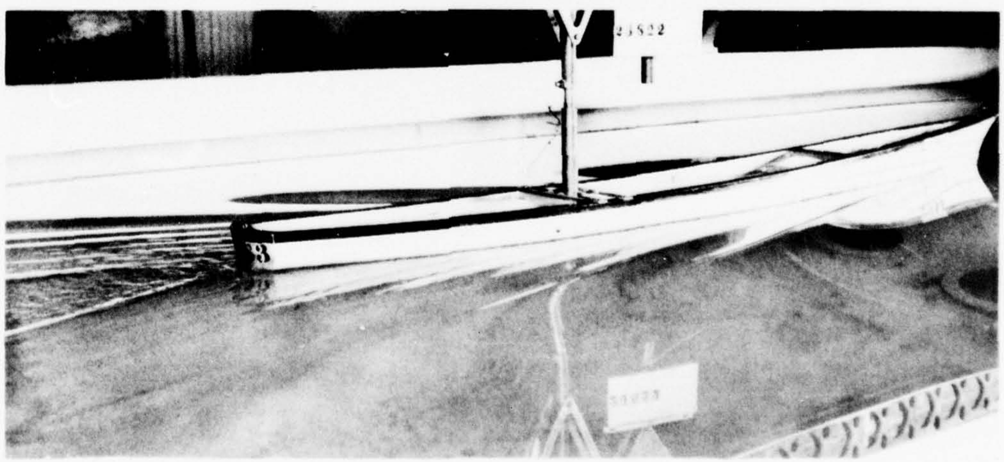
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, NEW JERSEY
TEST 2983-1A
BARE HULL NO APPENDAGES

1/80 SCALE MODEL - 480-FOOT DESTROYER
GIBBS & COX INCORPORATED

DISPL. = 5380 Tons   L.C.G. = ______
DRAFT = 16' 0" V_s = 20.38 kts
TRIM = Level

Figure 13. Wave Profile - Basic Hull - 20.38 Knots, Bow - 23821



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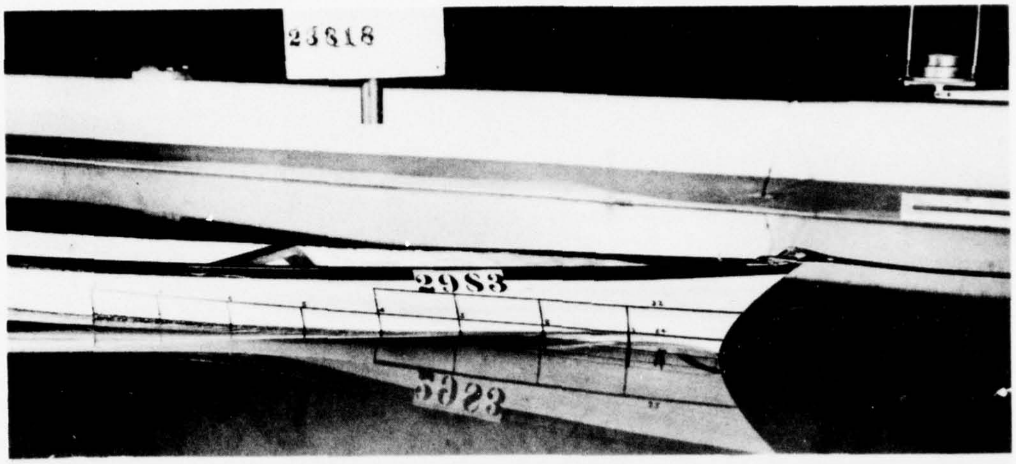
HOBOKEN, NEW JERSEY
TEST 2983-1A
BARE HULL NO APPENDAGES

1/80 SCALE MODEL, 480-FOOT DESTROYER
GIBBS & COX INCORPORATED

DISPL. = 5380 Tons   L.C.G. = ______
DRAFT = 16' 0" V_s = 20.38 kts
TRIM = Level

Figure 14. Wave Profile - Basic Hull - 20.38 Knots, Stern - 23822



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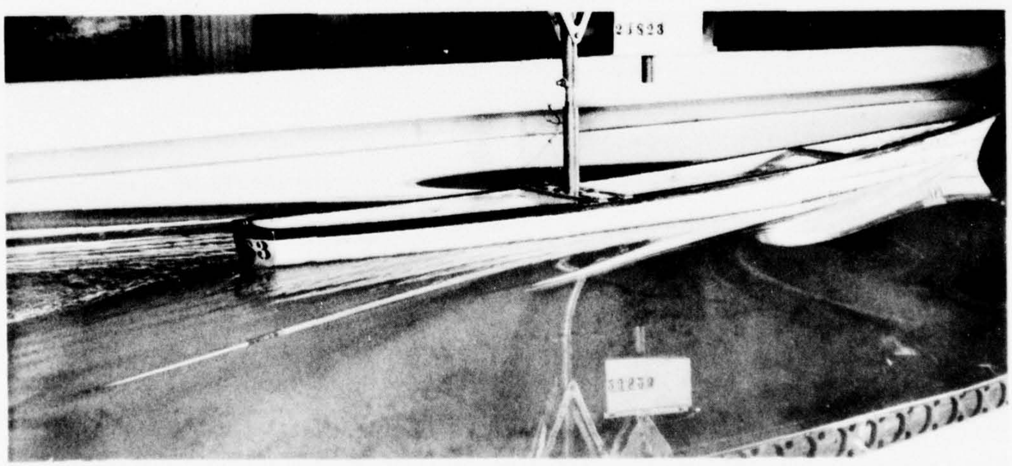
TEST 2983-1A
BARE HULL NO APPENDAGES

1/80 SCALE MODEL, 480-FOOT DESTROYER
GIBBS & COX INCORPORATED

DISPL. = 5380 Tons L.C.G. = ____
DRAFT = 16' 0'' V_s = 24.85 kts
TRIM = Level

Figure 15. Wave Profile - Basic Hull - 24.85 Knots, Bow - 23818



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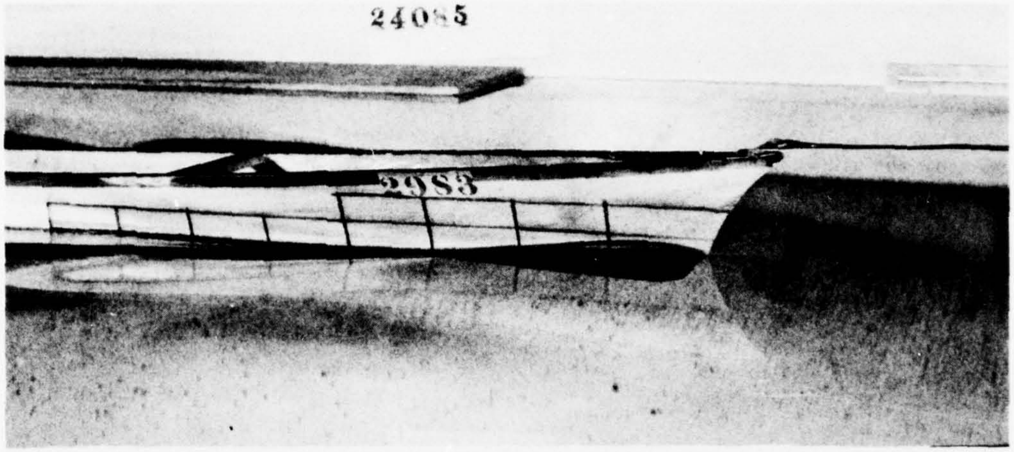
TEST 2983-1A
BARE HULL NO APPENDAGES

1/80 SCALE MODEL, 480-FOOT DESTROYER
GIBBS & COX INCORPORATED

DISPL. = 5380 Tons L.C.G. = ____
DRAFT = 16' 0'' V_s = 24.85 kts
TRIM = LEVEL

Figure 16. Wave Profile - Basic Hull - 24.85 Knots, Stern - 23823

C024-47003



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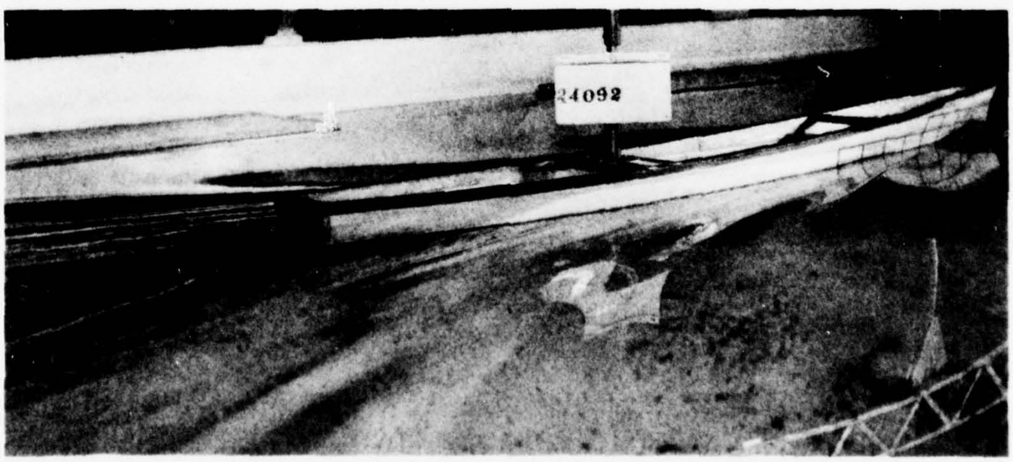
HOBOKEN, NEW JERSEY
DOME FOR 10'-0" x 100'-0" PLANAR ARRAY; 24" DEEP; RECESSED INTO HULL

480' DESTROYER - MODEL 2983(9I)
GIBBS & COX, INC.

DISPL. = 5,552 tons L.C.G. = ____
DRAFT = 16' 0" V_s = 20.38 kts
TRIM = ____

Figure 17. Wave Profile - 10′ by 100′ Recessed, Number 9 - 20.38 Knots, Bow - 24085



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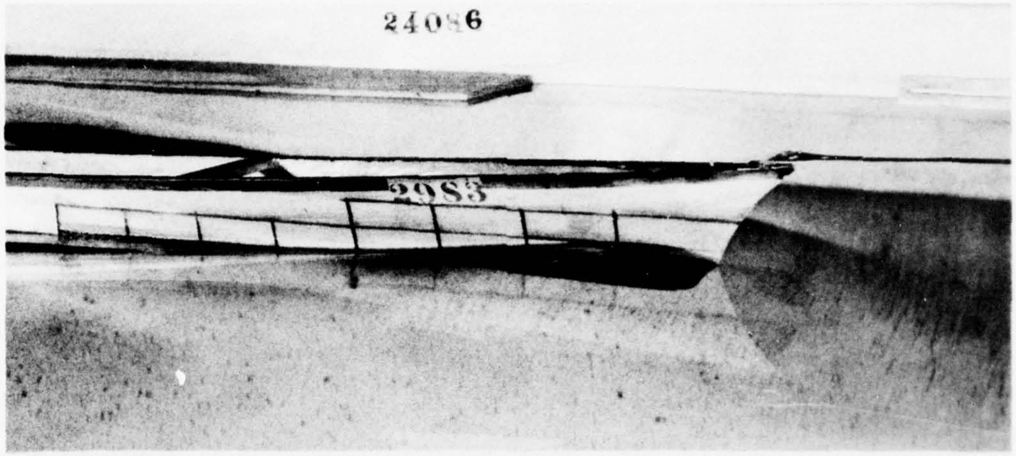
DOME FOR 10'-0" x 100'-0" PLANAR ARRAY; 24" DEEP; RECESSED INTO HULL

480' DESTROYER - MODEL 2983(9I)
GIBBS & COX, INC.

DISPL. = 5,552 tons L.C.G. = ____
DRAFT = 16' 0" V_s = 20.38 kts
TRIM = ____

Figure 18. Wave Profile - 10′ by 100′ Recessed, Number 9 - 20.38 Knots, Stern - 24092



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HOBOKEN, NEW JERSEY

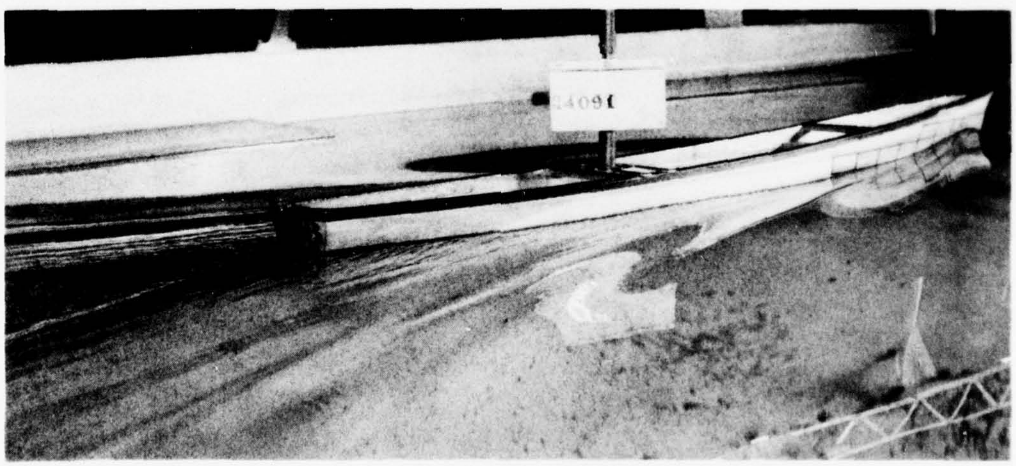
DOME FOR 10'-0" × 100'-0" PLANAR ARRAY; 24" DEEP; RECESSED INTO HULL

480' DESTROYER - DL MODEL 2983(91)

GIBBS & COX, INC.

DISPL. = 5,552 tons L.C.G. = ______
DRAFT = 16' 0" V_s = 24.85 kts
TRIM = ______

Figure 19. Wave Profile - 10' by 100' Recessed, Number 9 - 24.85 Knots, Bow - 24086



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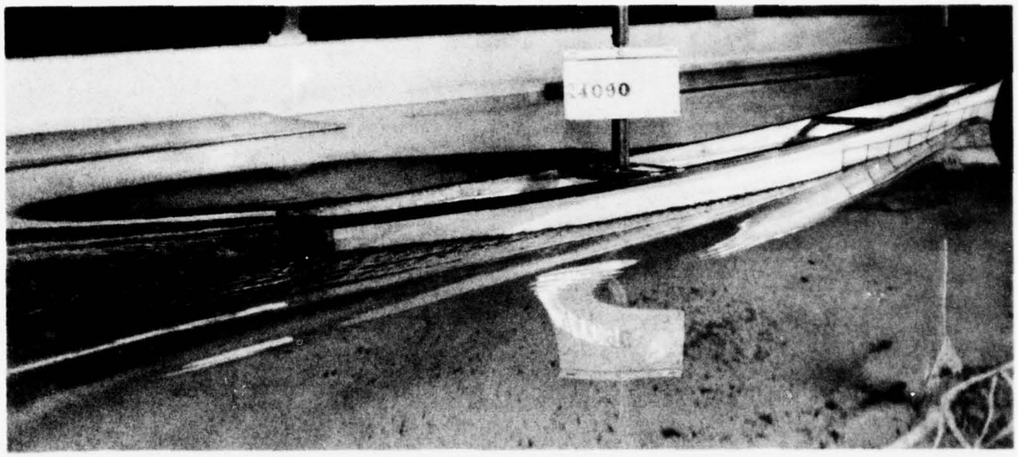
DOME FOR 10'-0" × 100'-0" PLANAR ARRAY; 24" DEEP; RECESSED INTO HULL

480' DESTROYER - DL MODEL 2983(91)

GIBBS & COX, INC.

DISPL. = 5,552 tons L.C.G. = ______
DRAFT = 16' 0" V_s = 24.85kts
TRIM = ______

Figure 20. Wave Profile - 10' by 100' Recessed, Number 9 - 24.85 Knots, Stern - 24091



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DOME FOR 10'-0" x 100'-0" PLANAR ARRAY; 24" DEEP; RECESSED INTO HULL

480' DESTROYER - DL MODEL 2983(91)

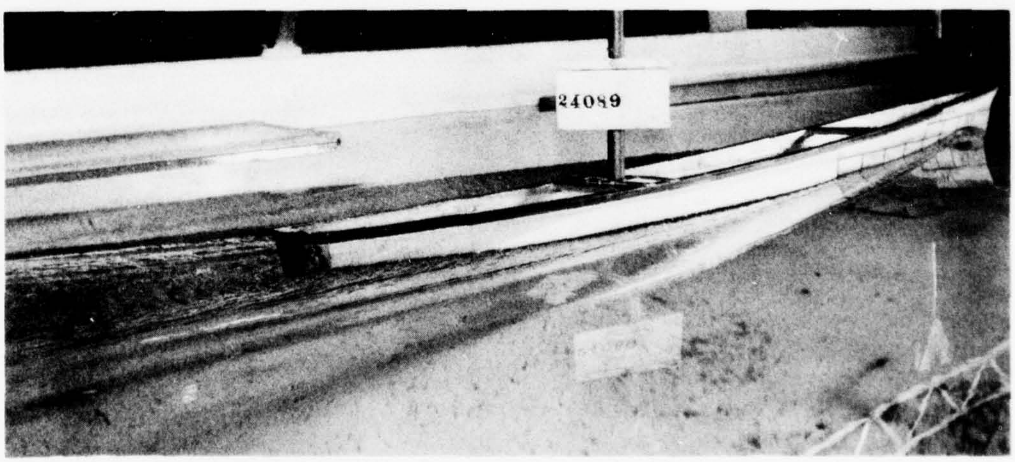
GIBBS & COX, INC.

DISPL. = 5.552 tons L.C.G. = ____

DRAFT = 16' 0" V_s = 34.32 kts

TRIM = ____

Figure 21. Wave Profile - 10' by 100' Recessed, Number 9 - 34.32 Knots, Stern - 24090



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DOME FOR 10'-0" x 100'-0" PLANAR ARRAY; 24" DEEP; RECESSED INTO HULL

480' DESTROYER - MODEL 2983(91)

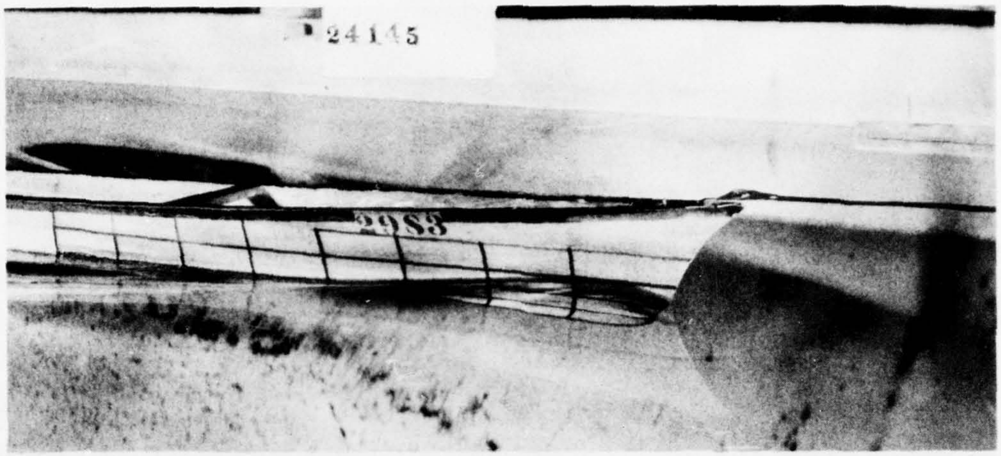
GIBBS & COX, INC.

DISPL. = 5.552 tons L.C.G. = ____

DRAFT = 16' 0" V_s = 40.02 kts

TRIM = ____

Figure 22. Wave Profile - 10' by 100' Recessed, Number 9 - 40.02 Knots, Stern - 24089



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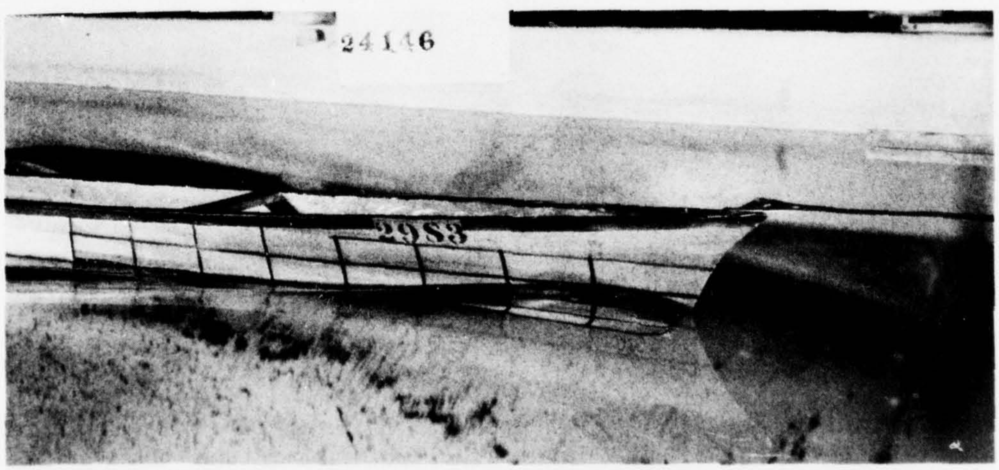
PLANAR ARRAY 10'-0"x70'-0"x24" DEEP (RECESSED IN HULL)

480' DESTROYER, MODEL 2983(11K)
GIBBS & COX, INC.

DISPL. = 5469 tons   L.C.G. = ____
DRAFT = 16' 0" V_s = 20.38 kts
TRIM = Level

Figure 23. Wave Profile - 10' by 70' Recessed, Number 11 - 20.38 Knots, Bow - 24145



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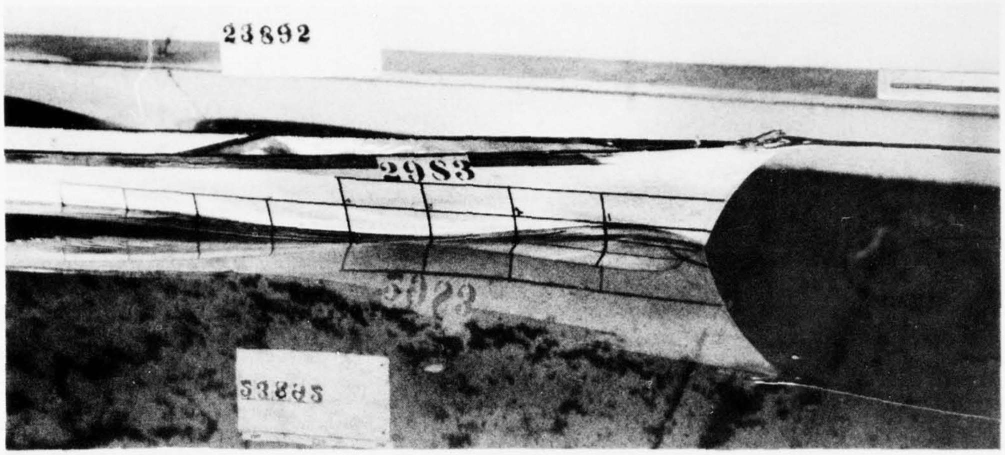
DOME FOR 10'-0" x 70'-0" x 24"DEEP PLANAR ARRAY; RECESSED IN HULL

480' DESTROYER, MODEL 2983(11K)
GIBBS & COX, INC.

DISPL. = 5469 tons   L.C.G. = ____
DRAFT = 16' 0" V_s = 24.80 kts
TRIM = LEVEL

Figure 24. Wave Profile - 10' by 70' Recessed, Number 11 - 24.80 Knots, Bow - 24146



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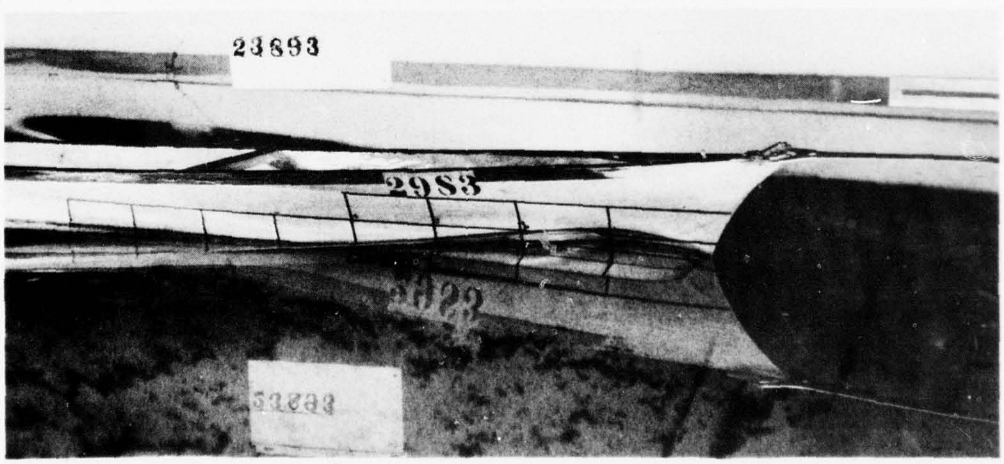
HOBOKEN, NEW JERSEY
DL 2983, TEST 3C
14'-0" x 70'-0" PLANAR ARRAY

1/80-SCALE MODEL, 480' DESTROYER
GIBBS & COX, INC.

DISPL. = 5,668 tons L.C.G. = ____
DRAFT = 16' 0" V_s = 20.38 kts
TRIM = Level

Figure 25. Wave Profile - 14′ by 70′, Number 3 - 20.38 Knots, Bow - 23892

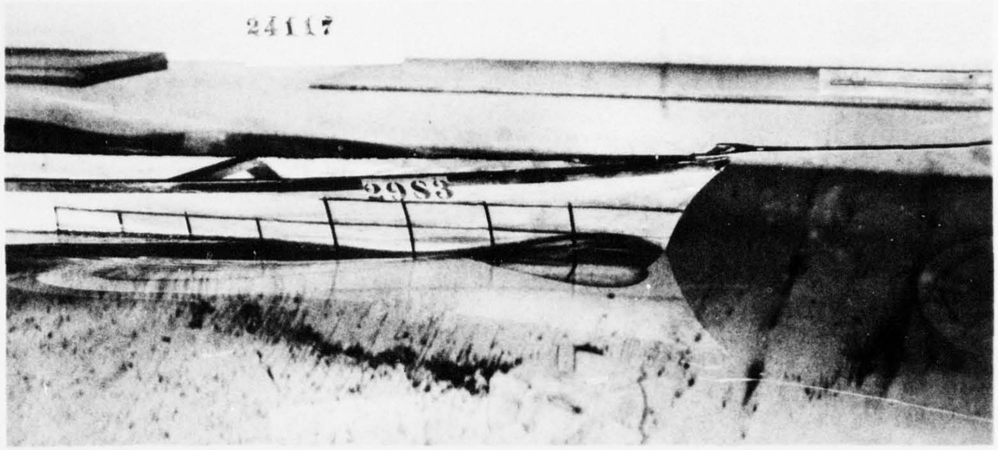


DAVIDSON LABORATORY
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, NEW JERSEY
MODEL 2983-3C
14'-0" x 70'-0" PLANAR ARRAY

1/80-SCALE MODEL, 480' DESTROYER
GIBBS & COX, INC.

DISPL. = 5,668 tons L.C.G. = ____
DRAFT = 16' 0" V_s = 24.85 kts
TRIM = Level

Figure 26. Wave Profile - 14′ by 70′, Number 3 - 24.85 Knots, Bow - 23893



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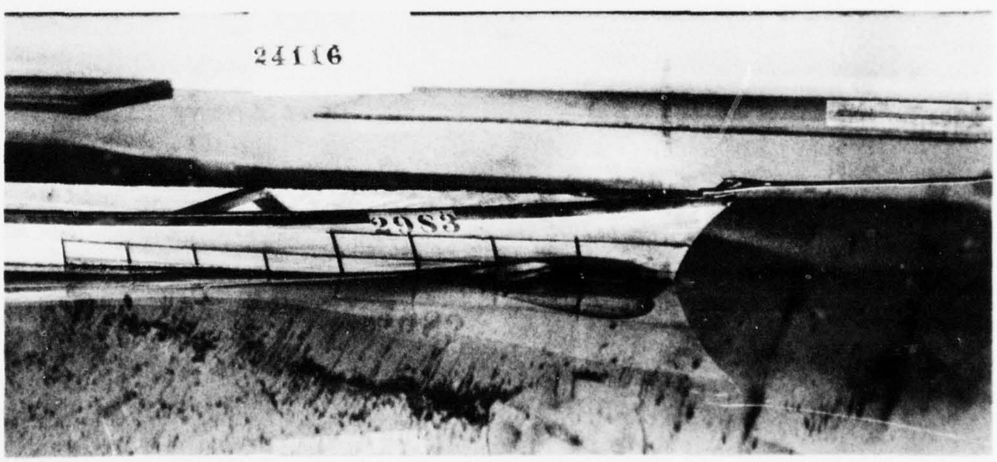
HOBOKEN, NEW JERSEY

SQS-26 TRANSDUCER DOME

480' DESTROYER - MODEL 2983(10J)
GIBBS & COX, INC.

DISPL. = 5514 tons
DRAFT = 16' 0"
TRIM = Level
L.C.G. =
V_s = 20.38 kts

Figure 27. Wave Profile - AN/SQS-26, Number 10 - 20.38 Knots, Bow - 24117



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DAVIDSON LABORATORY
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, NEW JERSEY

SQS-26 TRANSDUCER DOME

480' DESTROYER - MODEL 2983(10J)
GIBBS & COX, INC.

DISPL. = 5514 tons
DRAFT = 16' 0"
TRIM = Level
L.C.G. =
V_s = 26.74 kts

Figure 28. Wave Profile - AN/SQS-26, Number 10 - 26.74 Knots, Bow - 24116

In addition, underwater photographs of the model were taken at several speeds during each test in order to show flow behavior in the region of the bow domes. The photographs were taken at angles of 22-1/2 degrees and 67-1/2 degrees, measured from the vertical, and a number of representative photographs, Figures 29 through 32, are included in this report.

The measurements of bow and stern sinkage or rise have been plotted for several array housing configurations and are shown in Figure 33. The general shape of these curves are typical for destroyer type ships. In general, the effect of these array housings is to reduce the tendency for the bow to rise and the stern to sink as the speed increases.

In accord with the normal practice of the Davidson Laboratory, Stevens Institute of Technology, turbulence stimulation was provided by towing a vertical strut just ahead of the model. Tests were run at each speed with a 0.04 inch diameter strut, a 1/8 inch strut, and without any strut. The model resistance reported at each speed was taken from a curve faired through the highest resistance point as measured by the three methods described above.

Measured model resistance data showed relatively little scatter or unfairness. The only noticeable scatter occurred in tests 1A and 8H, but this was limited to the lowest speed tested (10.57 knots), where larger than normal differences in resistance between the three methods of stimulation were found.

As stated previously, model resistance curves for test 5E were refaired, since it was judged that the curves used by the Davidson Laboratory could be improved to fit the test data more closely. This refairing had the effect of raising the ship resistance slightly for speeds above 20 knots. No other refairing for any other tests was necessary.

The full scale results of the resistance (effective horsepower) tests have been plotted and are shown in Figures 34 through 38, and are summarized in Table XIII. The method of plotting used in these figures has been chosen to indicate the penalties or gains in EHP relative to the basic hull with a normal bow. This type of comparison is the most meaningful since an absolute value of resistance for a hull fitted with a certain dome (array housing) configuration does not indicate the effect of the dome unless it is related to a basic hull. A comparison of one dome with its hull with another dome and fitted on a different hull would not give a valid indication of the relative performance of the domes (array housings). Effective horsepower for the basic hull is given in Figure 39.

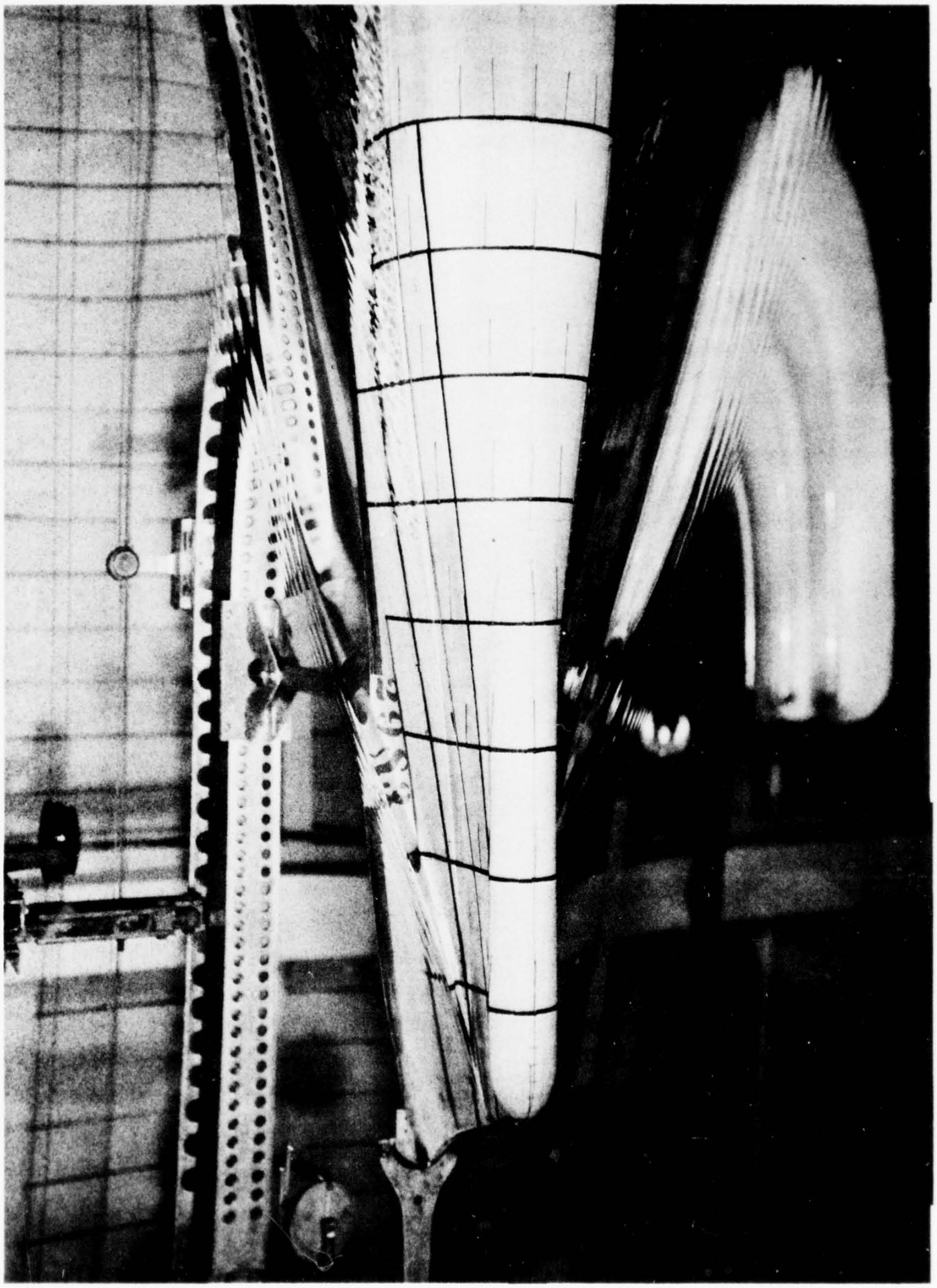
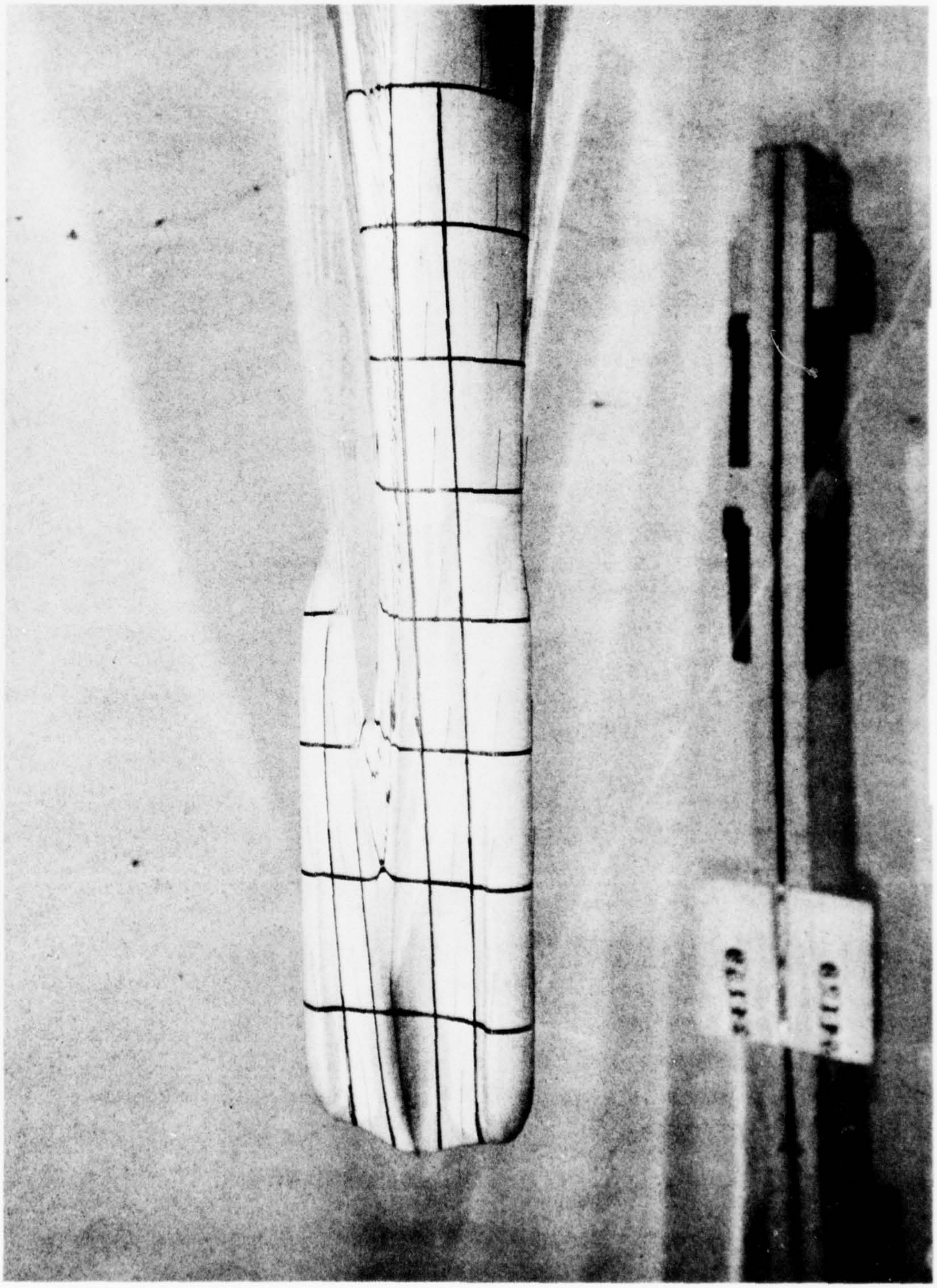


Figure 29. Flow - 10′ by 70′ Recessed, Number 11 - 24.80 Knots, 22-1/2 Degrees



480' DESTROYER, MODEL 2983(11K)
GIBBS & COX, INC.
DOME FOR 10'-0" x 70'-0" x 24" DEEP
PLANAR ARRAY: RECESSED IN HULL

SPEED: 24.80 KTS
TRIM: LEVEL
PORT: 67-1/2 DEG

Figure 30. Flow - 10' by 70' Recessed, Number 11 - 24.80 Knots, 67-1/2 Degrees

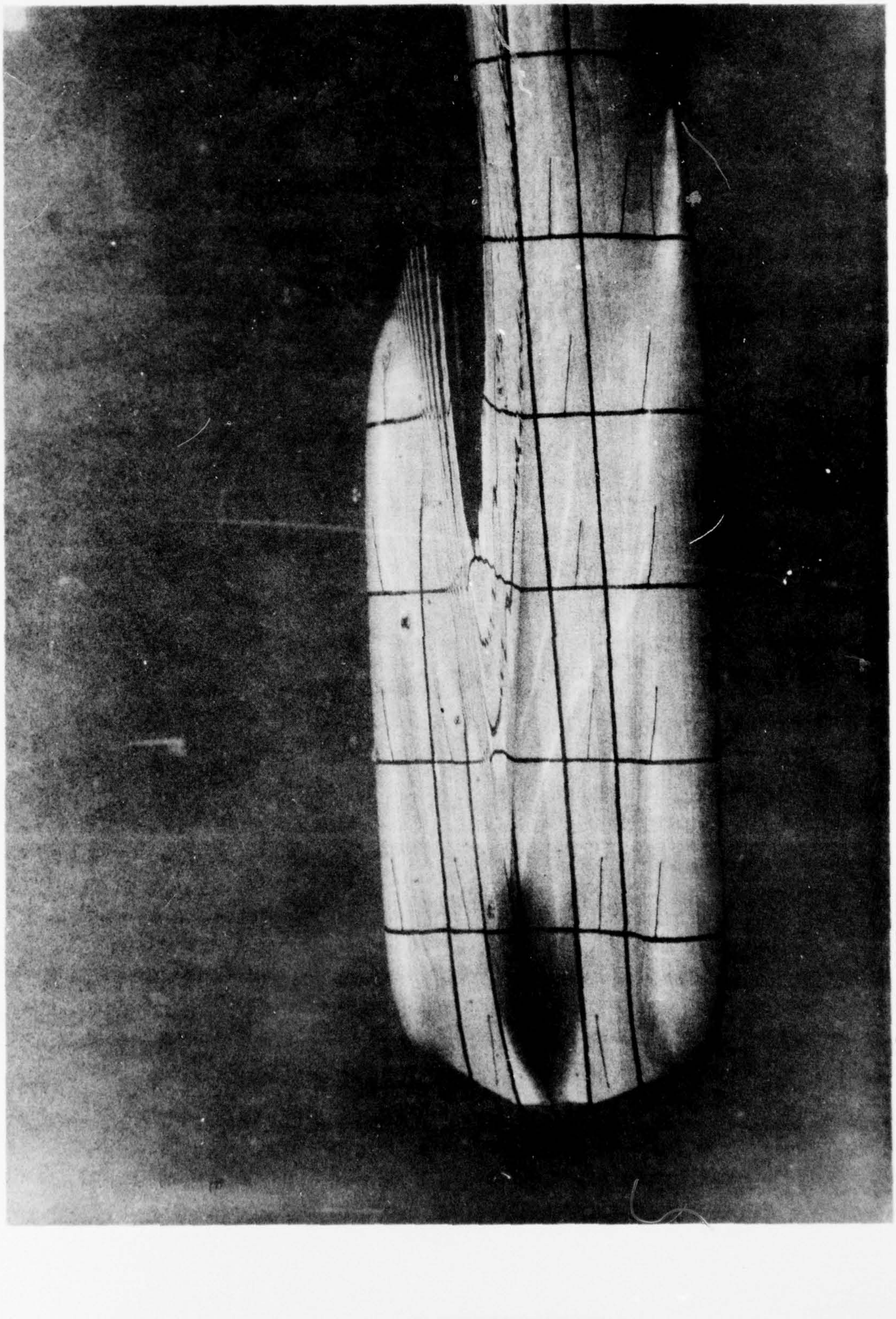


Figure 31. Flow - 14' by 70', Number 3 - 24.80 Knots, 67-1/2 Degrees

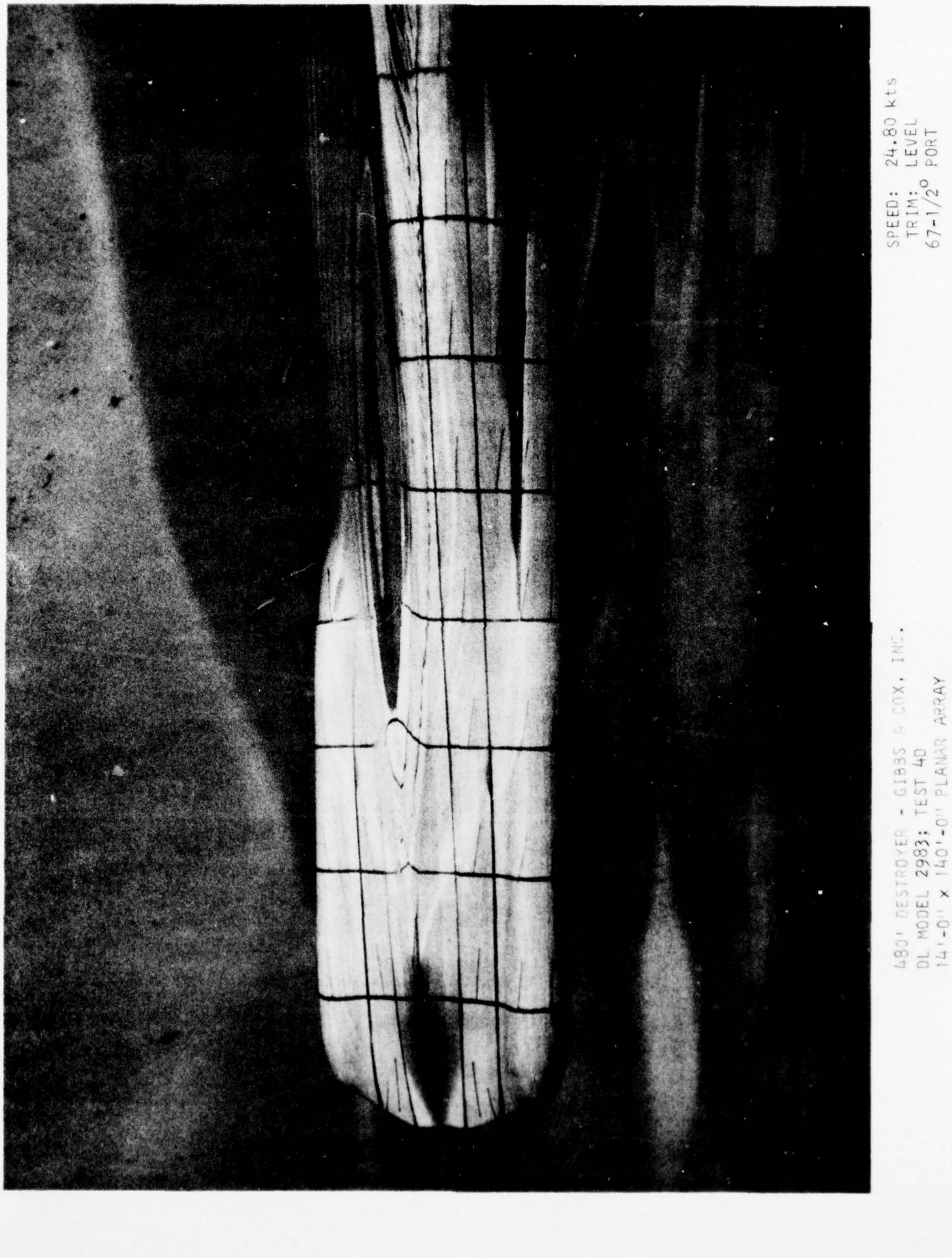


Figure 32. Flow - 14′ by 140′, Number 4 - 24.80 Knots, 67-1/2 Degrees

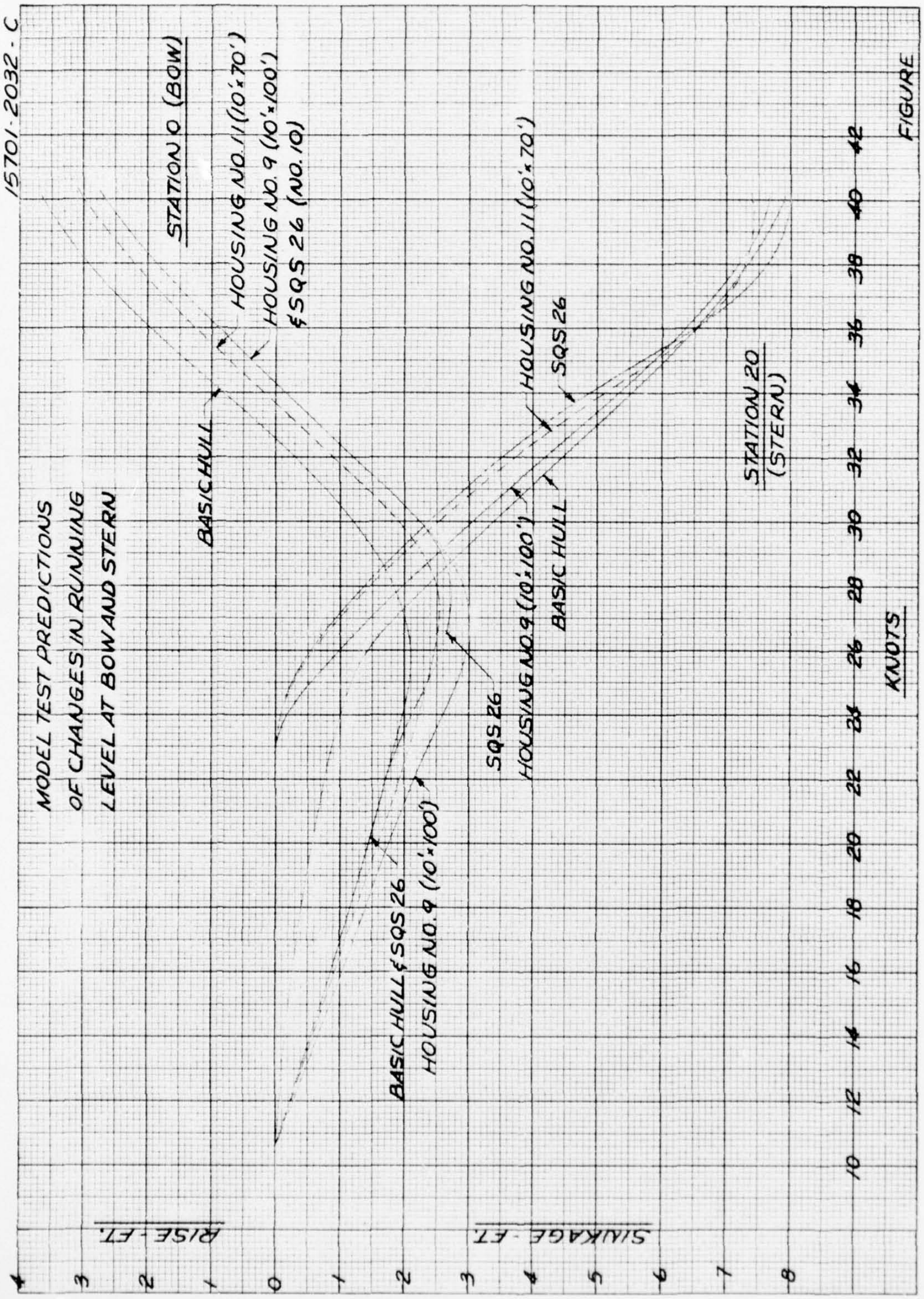


Figure 33. Changes in Running Level (Trim)

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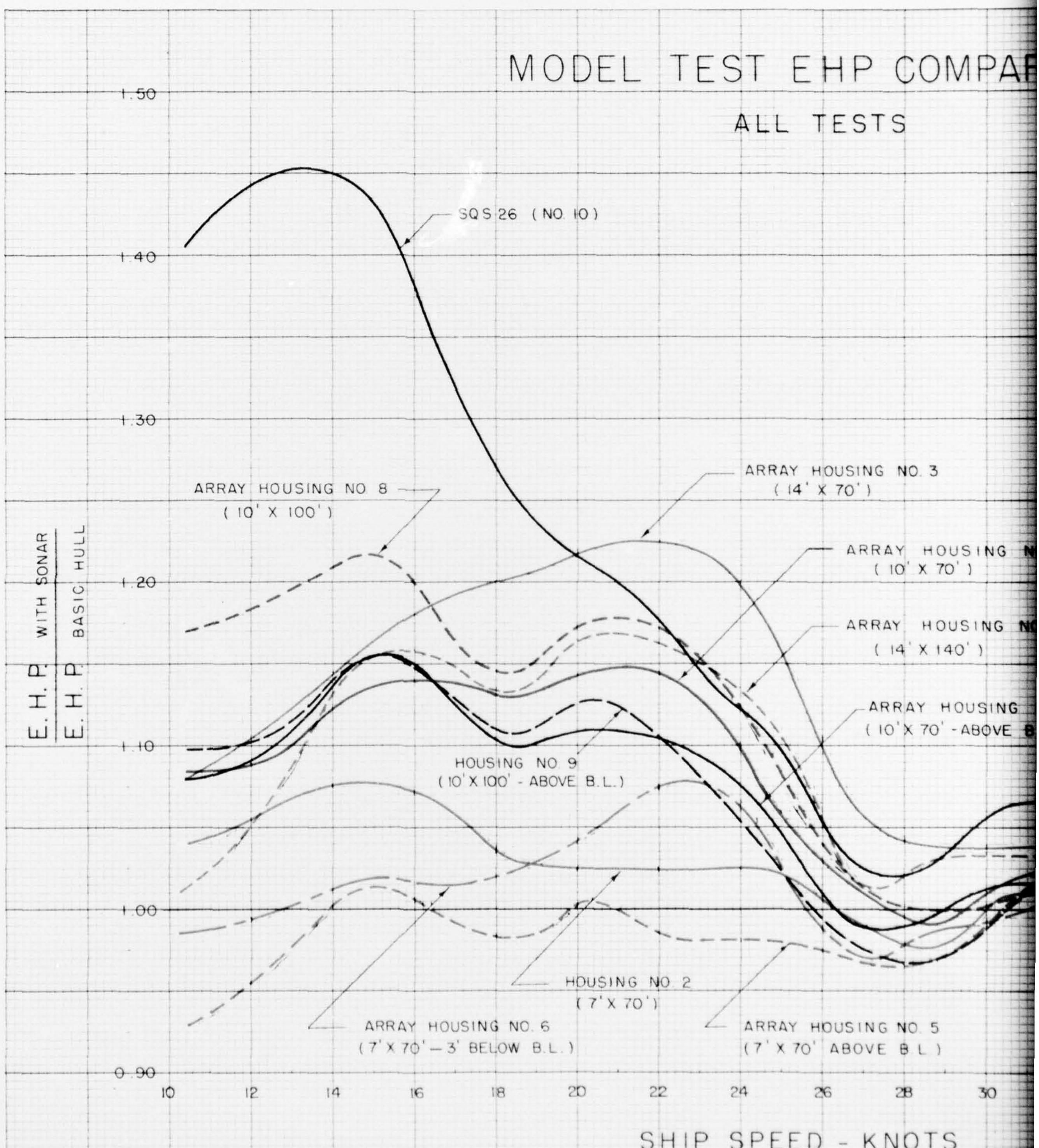

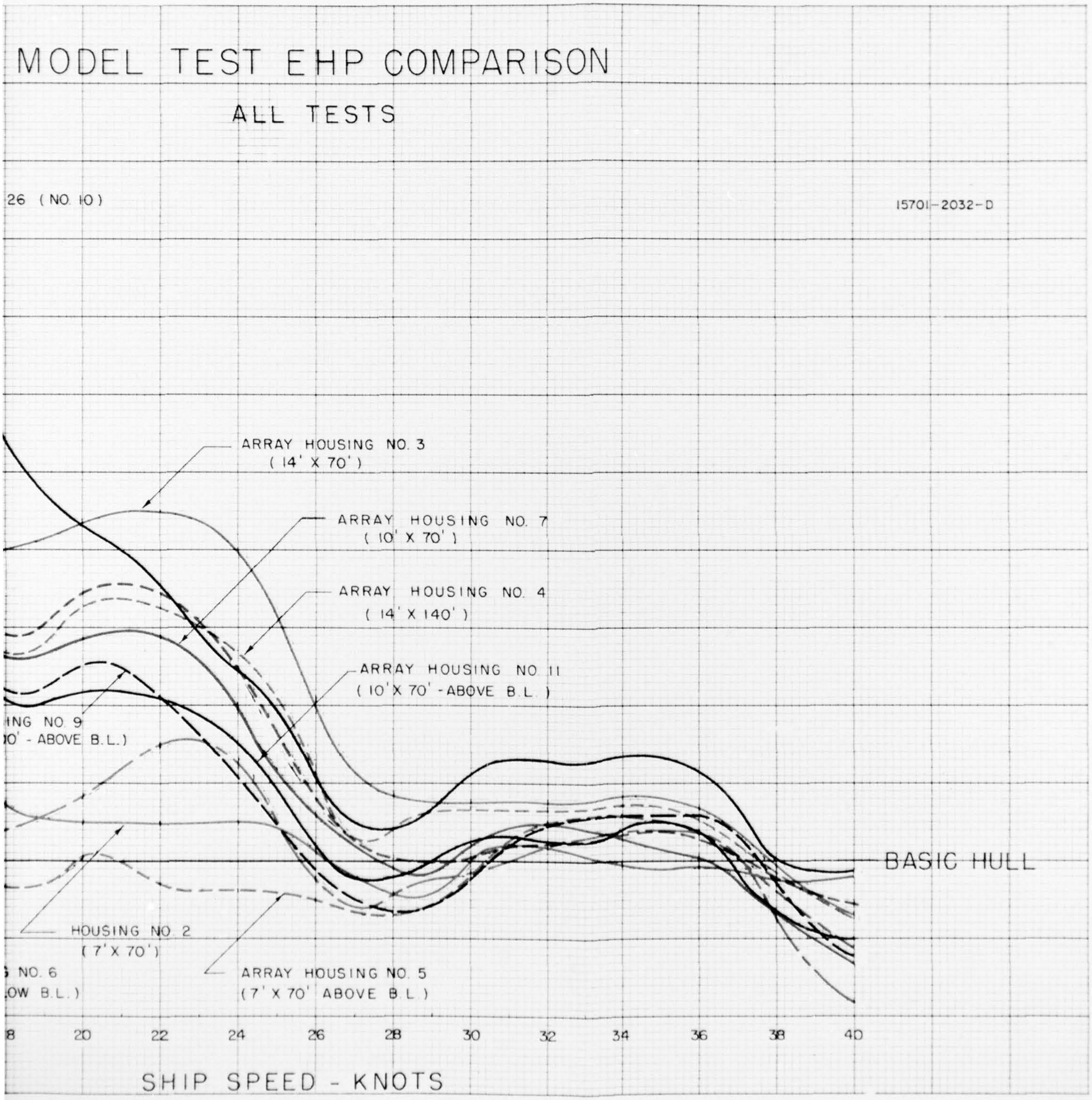

Figure 34. EHP/EHP - All Tests

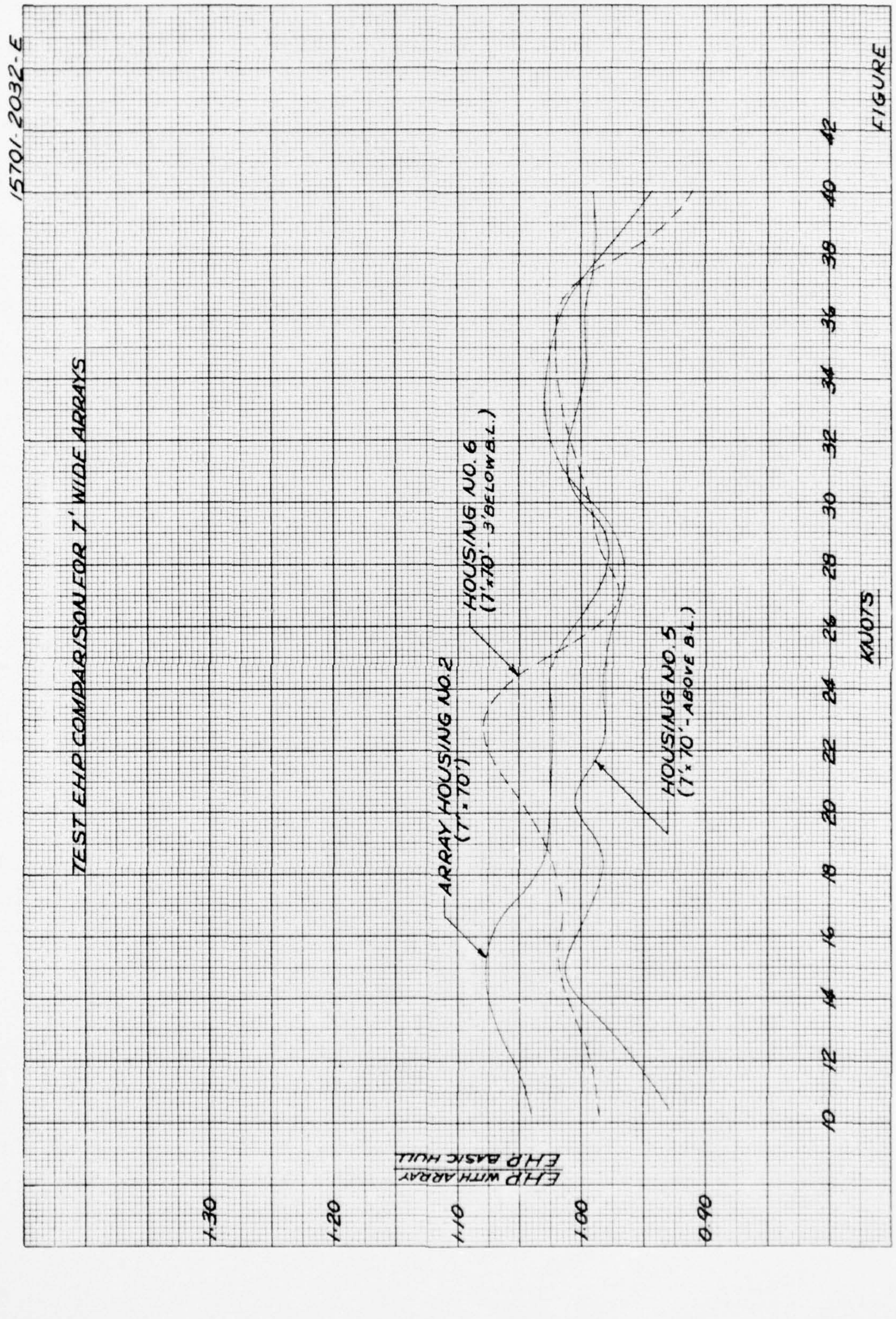

Figure 35. EHP/EHP - for Seven Feet Wide Arrays

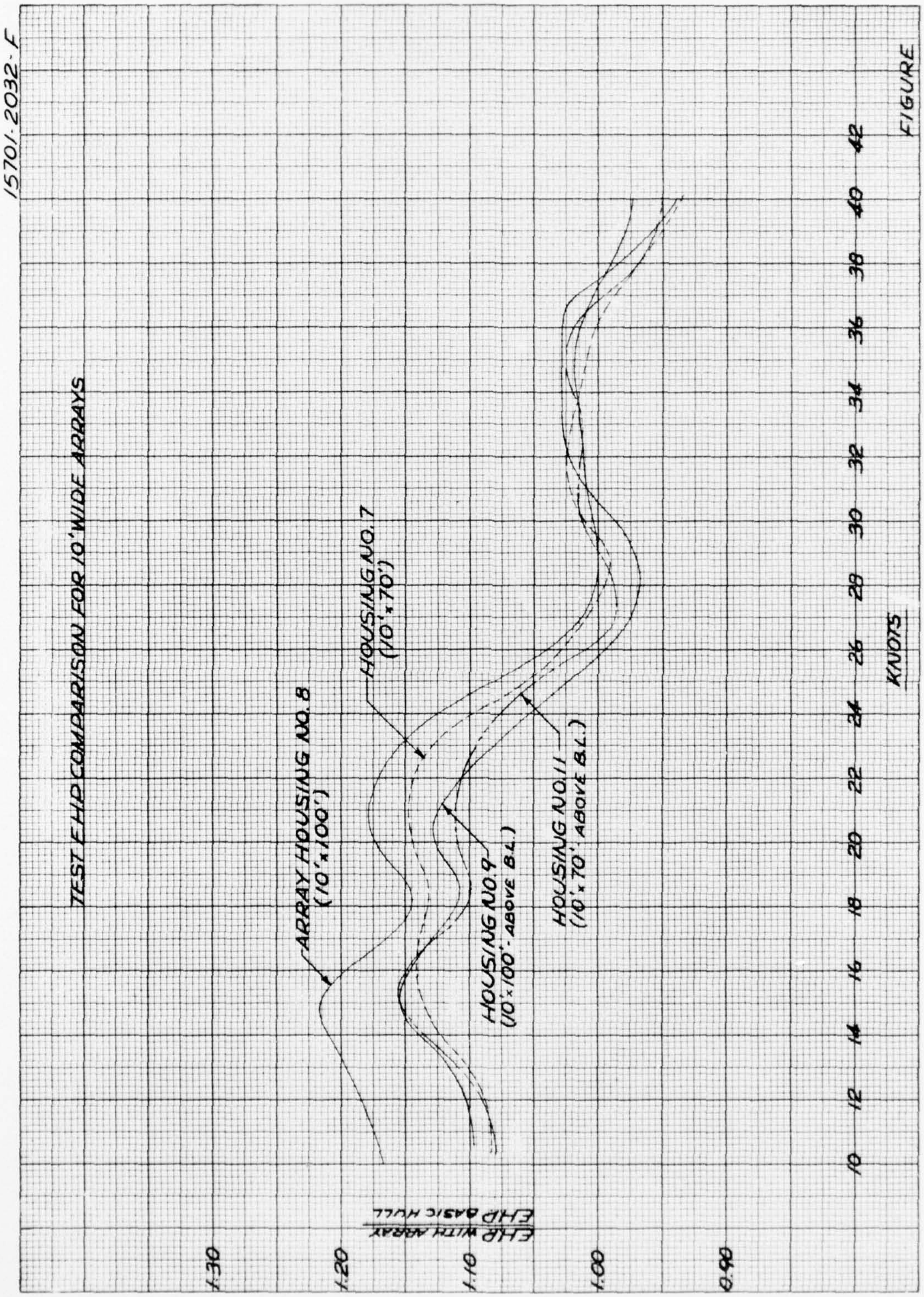

Figure 36. EHP/EHP - for 10 Feet Wide Arrays

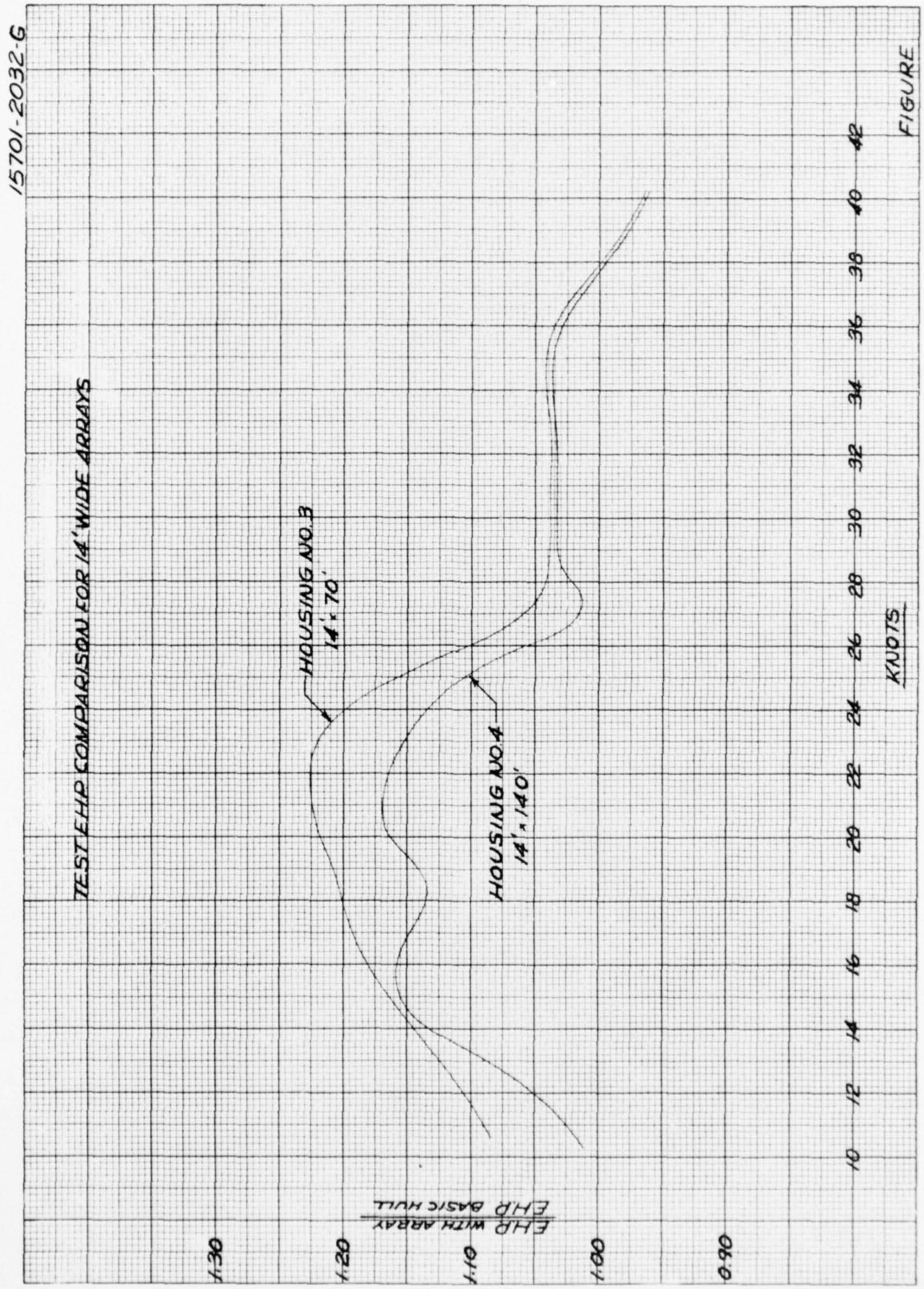

Figure 37. EHP/EHP - for 14 Feet Wide Arrays

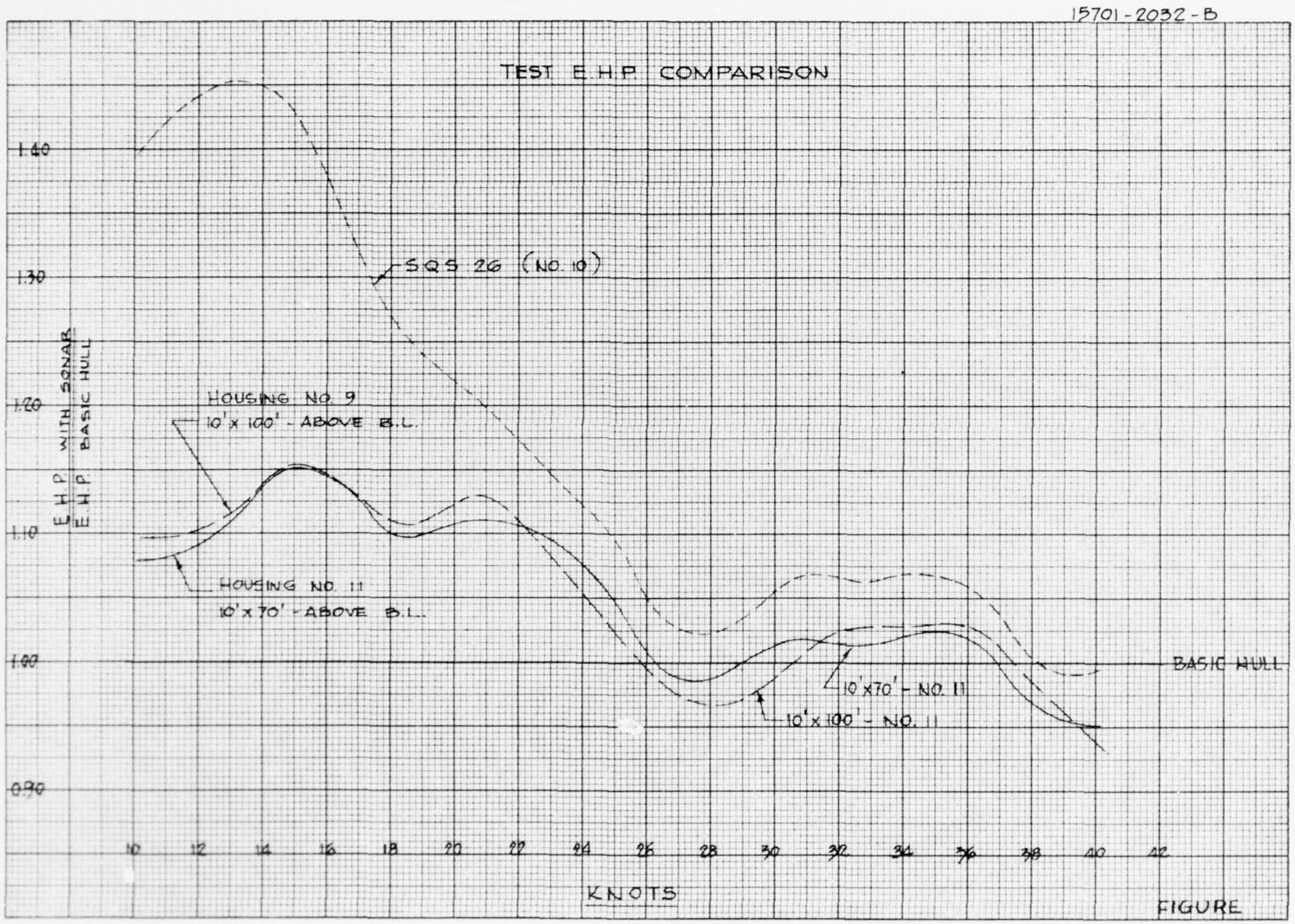

Figure 38. EHP/EHP - for 10 Feet Wide Arrays and AN/SQS-26 Dome

15701-2032-H

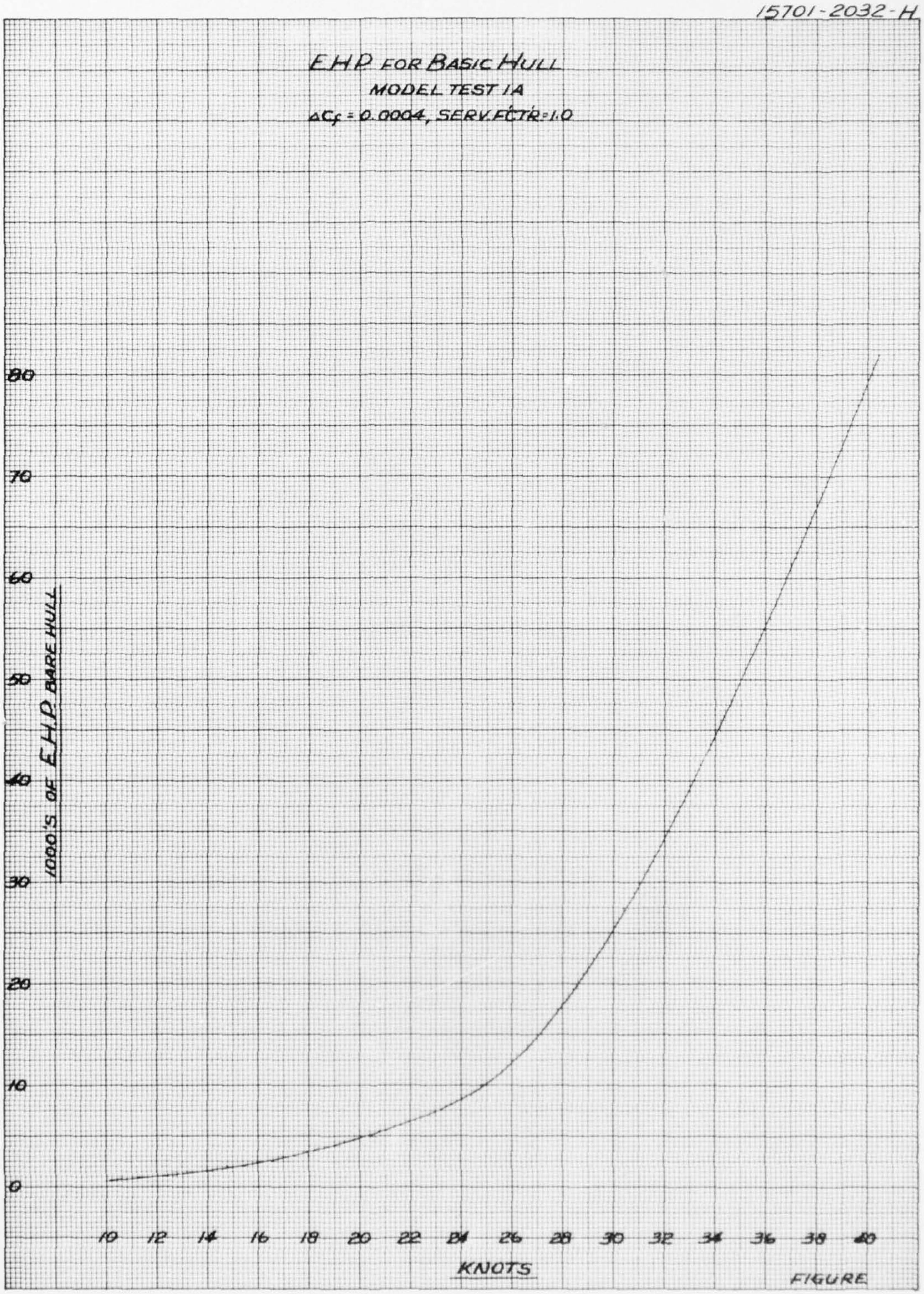

Figure 39. EHP versus Speed for Basic Hull

TABLE XIII

COMPARISON OF RESULTS OF MODEL TESTS

Housing No.	1		2		5		6		3		4		7		8		9		11		10	
Array Size Location Fig. No.	Basic Hull 1		7' x 70' x 12" Medium 2		7' x 70' x 12" High 3		7' x 70' x 12" Low 4		14' x 70' x 12" Medium 5		14' x 140' x 12" Medium 5		10' x 70' x 24" Medium 6		10' x 100' x 24" Medium 6		10' x 100' x 24" High 8&10		10' x 70' x 24"R High 7&9		SQS-26	
Displ. Tons Wetted Surf.	5380 25470		5464 26190		5416 25770		5525 26770		5668 27020		5807 27420		5566 26690		5618 26920		5552 26490		5467 26040		5514 26700	
	EFFECTIVE HORSEPOWER, PER CENT INCREASE FROM BASIC HULL																					
Speed Knots		%		%		%		%		%		%		%		%		%		%		%
14.78	1851	0	1994	7.7	1876	1.4	1883	1.7	2147	16.0	2132	15.2	2099	13.4	2253	21.7	2134	15.3	2132	15.2	2661	43.8
20.38	5088	0	5214	2.5	5115	0.5	5337	4.9	6216	22.2	5943	16.8	5883	15.6	5991	17.7	5743	12.9	5647	11.0	6163	21.1
24.85	9893	0	10130	2.4	9709	-1.9	10229	3.4	11528	16.5	11004	11.2	10500	6.1	10770	8.9	10170	2.8	10410	5.2	10890	10.1
34.32	46165	0	45970	-0.4	47386	-2.6	46270	0.2	48047	4.1	47820	3.6	46730	1.2	47020	1.9	47500	2.9	47220	2.3	49340	6.9
40.02	79370	0	78670	-0.9	74942	-5.6	72287	-8.9	76728	-3.3	76500	-3.6	74180	-6.5	77320	-2.6	74510	-6.1	75460	-4.9	78880	-0.6
Inc. in Displ.	0		84		36		145		288		427		186		238		172		87			
Water in Dome	0		38		36		36		107		197		93		129		129		93			
Net Incr. in Disp.	0		46		0		109		181		230		93		109		43		-6			
Wt. of Array Diff.													55 38		78 31		78 -35		55 -61			

The full scale resistance predictions are believed to give a reasonable indication of the magnitude of the effect of the various housings on resistance. It is recognized that difficulties can be expected in establishing adequate turbulence, particularly over appendages such as sonar domes or array housings located near the bow, with a relatively small model as used in these tests. For this reason, accuracy in predictions usually achieved with larger models cannot be expected. However, it is noted that the shapes of the curves compare well generally, and that comparisons of the results for similar domes indicate that good repeatability of data was achieved through most tests. It is also noted that the relative increases or decreases in resistance for the various array housings show trends which are, in general, reasonably consistent.

Examination of the full scale results reveals several trends which are discussed below:

1) Throughout most of the speed range, the installation of sonar housings tested in this program cause an increase in hull resistance. The housing for the 7 feet by 70 feet planar array located 18 inches above the base line (array housing no. 5) is an exception to this trend.

2) In general, as ship speed increases, the effect of the sonar domes on resistance becomes smaller.

3) For most planar array housings tested an improvement in performance over the AN/SQS-26 bow dome (currently used by the Navy) is indicated throughout the speed range. This improvement is substantial at lower speeds.

4) The effect on resistance of raising the conformal/planar array above the base line is beneficial throughout most of the speed range.

5) In general, an increase in the width of the conformal/planar array housing causes an increase in resistance. For the speed range from 20 to 25 knots, changes in array width have an important effect on resistance.

6) The effect of changes in the length of the conformal/planar array housing is moderate. For the 10-foot wide arrays, an increase in length does not show any clear cut advantage. For the 14-foot wide arrays, an increase in length offers some gain for speeds below 28 knots.

In all cases, the addition of an array housing results in an increase in wetted surface and a corresponding increase in frictional resistance. The effect of the array housing on residuary resistance depends upon a number of factors which include hull displacement, speed, the phase relationship of the wave systems originating due to the hull and due to the sonar dome (array housing), the form and interference drag of the dome or housing, and the effect of the dome or housing on running trim.

Variations in residuary resistance are sufficient to cause wide variations in total resistance. The increase in EHP which occurs in the lower speed range for some of the domes is largely accounted for in this way. Conversely, it is the reduction in residuary resistance due to the effect of the sonar dome or array housing which accounts for those cases where, in certain speed ranges, the total resistance is less than that of the basic hull with a normal bow.

The significant improvement in resistance characteristics of several of the conformal/planar array housings as compared to the AN/SQS-26 dome has been accomplished by improving the hydrodynamic design so that the residuary resistance is considerably reduced. Some evidence of this can be seen by comparing Figures 17 and 23 with Figure 27 which shows bow wave profiles for array housings number 9 and 11, and for the AN/SQS-26 dome. The latter dome produces a more pronounced hollow and secondary bow wave immediately aft of the bow wave. The effect of changes in the wave profile at the bow on sonar performance is not fully understood, though it is believed that any flattening of the wave profile will cause the bubble path to occur further aft along the hull.

Examination of flow photographs reveals no noticeable flow separation or eddying. For the conformal/planar array housings, the flow has a small downward component as it passes the widest portion of the dome, as can be seen in Figures 30 to 32. Flow characteristics of conformal/planar array housings should be investigated in more detail using a larger model size.

Since these tests were conducted in still water, there is no indication of the effect of the various array housing configurations on ship motions or on sonar performance in a seaway. As previously noted, the effect of raising the planar array above the base line on resistance in still water is advantageous. It is believed that this location may also offer a further advantage, since the hull itself may serve to baffle some of the noise radiated from the propellers. The selection of the vertical location of planar arrays must await the investigation of the effect of changes to this location on both ship and sonar performance in waves.

The sections at the forward end of the conformal/planar array housings have been chosen to provide good resistance to flow cavitation inception. However, no measurements were made during this test program. Final detail design of the array housing or dome shape should be made on the basis of an investigation of cavitation.

SECTION IV
CONCLUSIONS AND RECOMMENDATIONS

It is feasible to fabricate and install sonar array housing suitable for accommodating horizontal planar arrays which are located well forward in the ship near the keel.

Preliminary results of trade-off analysis between sonar capabilities and hydrodynamic performance indicate that the 10-feet wide arrays incorporated in array housings number 9 and 11 represent the best trade-off between sonar performance and ship resistance. Array housings number 9 and 11 have been selected for further model testing at the David Taylor Model Basin (DTMB), in order to confirm the performance predictions reported herein and to investigate the effect of array housing or dome design on ship maneuvering, directional stability, sea keeping and rolling, local flow behavior, and cavitation inception.

Subject to confirmation by tests with larger hull models, the selected conformal/planar array housings (numbers 9 and 11) offer significantly improved hull resistance characteristics in comparison with the standard AN/SQS-26 sonar dome currently used on destroyer type ships. This improvement exists throughout the speed range from 10 knots to 40 knots. The improvement in the speed range between 20 knots and 25 knots will have a significant effect on cruising radius.

The location of the horizontal planar array above the base line offers improved hull resistance performance. In this location the hull may also serve to some extent as a baffle against noise originated at the propellers. The best vertical location of the array should be selected after further study and review of sea-keeping test data results.

Except for the widest housings investigated, changes in array housing length have a relatively small effect on hull resistance. Other considerations such as dry docking, total system weight, space, array structural attachment details, basic ship structural strength et cetera must also be evaluated in determining the maximum permissible length of the horizontal planar array transducer and its associated housing.

The results obtained during this phase I test program are based upon a first cut effort in developing suitable horizontal planar array housings and in the iterative design processes scheduled for accomplishment upon receipt of the results of the current David Taylor Model Basin (DTMB) hydrodynamic tests, one could expect further improvements in array housing design performance when compared to the bare hull hydrodynamic resistance results.

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